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Impacts of Technology on U.S. Cropland and Rangeland Productivity

Volume II—Background Papers

Part A

Paper No.

1. How Agricultural Technologies Affect Productivity of Croplands and Rangelands by Affecting Microbial Activity in Soil
2. Impacts of Technologies on Range Productivity in the Mountain, Intermountain, and Pacific Northwest States
3. Livestock Grazing on the Forested Lands of the Eastern United States
4. Influences of Commodity Programs on Long-Term Land Productivity (Conservation)
5. Problems of Cost-Sharing Programs for Long-Term Conservation: The Example of the Agricultural Conservation Program
6. Impacts of Rangeland Technologies and of Grazing on Productivity of Riparian Environments in United States Rangelands
7. Data Base Assessment of Effects of Agricultural Technology on Soil Macrofauna and the Resultant Faunal Impact on Crop and Range Productivity

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Preface

This volume contains papers written for OTA to assist in preparation of the report *Impacts of Technology on U.S. Cropland and Rangeland Productivity.* OTA does not endorse these papers. In several instances, the OTA report reaches somewhat different conclusions because of additional information which was obtained later. These papers, however, may prove valuable for readers needing more detailed or specific information than could be accommodated in the final assessment report, and are being made available for such purposes.

Background Paper No. 1

HOW AGRICULTURAL TECHNOLOGIES AFFECT PRODUCTIVITY OF CROPLANDS AND RANGELANDS BY AFFECTING MICROBIAL ACTIVITY IN SOIL

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This background paper was prepared for the assessment "Impacts of Technology on U.S. Cropland and Rangeland Productivity." The views expressed are those of the author(s) and not necessarily those of OTA.

Background Paper No. 1

HOW AGRICULTURAL TECHNOLOGIES AFFECT PRODUCTIVITY OF CROPLANDS AND RANGELANDS BY AFFECTING MICROBIAL ACTIVITY IN SOIL

BASIS FOR CONCERN

Microorganisms residing in soil have a unique and critical function in the productivity of agricultural land, rangeland and forests because processes they carry out are essential for the growth of higher plants, and few economically feasible substitutes exist for their manifold functions. Because of the importance of these functions, the effects of agricultural technology on these populations and their activities must be evaluated carefully in order to determine whether such technology will bring about long-term deleterious changes in soil leading to a decline in society's future capacity to feed itself or to rid the environment of toxic substances.

A critical area of microbial function is to generate the nutrients that are essential for plant growth. Microorganisms are either the sole or the chief means for converting the unavailable forms of nitrogen, sulfur, phosphorus and other elements in soil to products that higher plants can utilize. In this way, the subterranean inhabitants carry out a series of reactions without which there could be little or no plant development, except in the special circumstance where crops could be grown entirely at the expense of fertilizers. Moreover, in many areas of the United States as well as elsewhere, the rate at which microorganisms convert organic nitrogen, as well as sometimes phosphorus, to inorganic products determines the rate of plant growth because it is this transformation, in the absence of fertilizer, that provides crops or range plants with the element that is most limiting to their productivity. Hence, any deleterious action on a microbial process that is critical to plant nutrition would have dire consequences.

The microscopic inhabitants also modify soil structure. They do this by forming humus and by binding together the minute particles of soil into larger aggregates. These structural components are beneficial because they promote root development, improve soil aeration and lead to better moisture relationships. Such activities are likewise important for the productivity of agricultural, range and forest lands.

These microscopic forms of life also are responsible for the decomposition of organic matter and the release of the elements in the organic materials. These elements may be converted to gaseous forms, as in the case of carbon and nitrogen, and it is by such conversions that microorganisms regulate the chemistry of the atmosphere as well as of the surface of the earth. This organic matter breakdown also affects the proliferation and interactions among microorganisms, the organic carbon being their nutrient sources. The microbial decay of plant remains is also useful inasmuch as some crop residues contain toxic substances, and the reason these toxins rarely harm living plants is that they are destroyed by microorganisms before their concentrations become high enough to be deleterious.

In addition, the microorganisms of soil are responsible for the decomposition of an enormous number of synthetic chemicals. These may be pesticides that are applied to soil or industrial wastes that are deliberately added as part of land disposal procedures or enter soil from inadvertent discharges. A large part of the atmospheric content of air pollutants is similarly destroyed as the lower portion of the atmosphere comes into contact with soil, where the microorganisms bring about the destruction of such toxic substances as carbon monoxide and various gaseous hydrocarbons. The significant role of microorganisms in destroying synthetic chemicals and other pollutants has only become of general knowledge in recent years.

Microorganisms in soil thus serve society at the present time and should continue to do so in the future. They are important now in food production, range lands, forest maintenance and in the destruction of pollutants. These organisms must maintain similar levels of activity in the future so that they will continue to serve society in the same ways and to the same or similar extents.

RATIONALE OF THIS OVERVIEW

In this position paper, methods to measure the impacts of agricultural technology on microbial activities or populations will be considered first. Who is performing the measurements and certain spatial and temporal aspects of the testing will then be considered. Then, the available information on the impact of agricultural technologies on microbial activities will be considered. In some cases, the body of data is vast, but the information will not be detailed owing to the lack of space. A few pertinent references are given, but these are only illustrative of the types of results that have been obtained. In other instances, the data base is quite sparse, and the information that exists is derived from but a few studies. The mechanisms that likely account for the effects on microorganisms subsequently will be discussed. The possibility that these soil inhabitants will acclimate to these stresses will be raised, and then the effect of soil properties on microbial responses will be considered. Finally, the adequacy of the data will be evaluated. At the end of the paper, a number of conclusions and recommendations are given.

TYPES OF MEASUREMENTS BEING MADE

Soil scientists and microbiologists have reached a general consensus on many of the types of tests to be conducted. However, there is disagreement whether the tests should be run on the entire soil community (which contains populations of many different microbial species) or on individual populations. In measuring effects on the soil community, the rate is often determined of some process which reflects not the activity of a single or a few similar organisms but rather a diverse group of microorganisms. Assessments of effects on the community are particularly valuable because they include the various biotic interactions and the complex processes affected by dissimilar microorganisms. On the other hand, certain reactions in soil are carried out by a narrow range of organisms, and a few of the processes brought about by individual populations may be especially important to the nutrition of plant; for example, nitrification.

Some investigators prefer to evaluate the impact of stresses by measuring changes in the numbers of organisms rather than the rates of processes; for example, modifications in the numbers of bacteria, actinomycetes or fungi or in discrete taxonomic categories of organisms. The investigators who assess effects on processes argue that the capacity of soil organisms to alter chemical substances is a physiological function and that stresses therefore should be evaluated in terms of their impact on the various biochemical transformations that occur.

A problem in assessing impacts on microorganisms or microbial processes is to select those processes or microorganisms that are critical for soil fertility and plant growth. Some reactions are unquestionably essential for plant development, but others may be only simulatory or of little immediate significance to plant productivity. The issue of essentiality is especially relevant in examining effects on categories of microorganisms rather than on processes because some microbial species probably could be eliminated from soil with little or no impact on the functioning of the soil ecosystem; the reason a species could be lost with little lasting effect is because of the enormous array of microorganisms in soil, many of which probably have similar if not identical functions. At the present time, however, it is not known which species can be lost and which are irreplaceable in the complex and highly heterogeneous soil environment.

The processes that have been most frequently tested in order to assess the impact of agricultural technology include the following. (a) The decomposition of soil organic matter. This simple assay involves testing for the evolution of carbon dioxide or the consumption of oxygen. The test is also a measurement of soil respiration. (b) Nitrogen mineralization, the conversion of the organic nitrogen native to soil (which is unavailable to higher plants) to inorganic products that plants can use. Because this process more than any other limits plant growth in many areas of the world, tests of nitrogen mineralization are particularly important. (c) Nitrification, the conversion of ammonium to nitrate. In the past, assessments of impacts on nitrification were considered to have a high priority because it was assumed that this process was critical for plant growth, but universal agreement on this assumption no longer exists. Nevertheless, nitrification is an important test because the responsible organisms appear to be among those most sensitive in soil to stress, so that a technology that has little or no effect on nitrification will probably have little or no influence on other major soil processes. (d) The decomposition of added organic materials. These determinations are frequently conducted because the rate of decomposition of native soil organic matter is slow, and a shorter test is sought to expedite the assessment of environmental impacts. In this assay, a simple organic chemical is added to a sample of soil, and the rate of its conversion to carbon dioxide or the rate at which microorganisms consume oxygen as they decompose the chemical is measured. (e) Nitrogen fixation, the utilization by microorganisms of gaseous nitrogen. This determination is facilitated by the availability of sensitive techniques to measure the rate at which nitrogen is removed from the atmosphere and incorporated into soil. Because the fixation of nitrogen by free-living microorganisms in soil is probably not of great consequence in the short-term, the significance of this test is not related to an immediate impact on food production; however, the return of nitrogen from the atmosphere to the soil is important in the long run, and hence this test gives valuable information.

In addition, assessments are often made of how particular stresses alter the numbers of individual categories of microorganisms; for example, bacteria, actinomycetes, fungi and, on occasion, algae. Means also exist to enumerate certain physiological or taxonomic categories or microorganisms, and the impact of some technologies on these groups has been occasionally examined.

Studies designed to ascertain the effects of environmental stresses on individual populations in artificial media are carried out because such populations are often easier to test and the data are easier to interpret. Such investigations have provided a large amount of information on the behavior of individual species functioning in isolation, but the data have limited utility in predicting what might happen under natural conditions. The chief reasons are: (a) the interactions among populations are ignored and (b) the microorganisms responsible for most biological processes in soil are unknown or are poorly defined.

On the other hand, studies of individual populations have demonstrated marked differences in sensitivity of microorganisms to particular stresses.

Thus, certain bacteria or algae are sensitive to low-level stresses, while other categories of microorganisms are quite resistant; for example, nitrifying populations are suppressed by modest levels of salts and pesticides, and certain groups of algae are sensitive to many herbicides and to increases in acidity. Although lichens are not important in biochemical transformations in agricultural and range lands, they are significant in the weathering of rocks and soil formation, and these microorganisms are inhibited by extremely low levels of certain air pollutants, in particular sulfur dioxide. Furthermore, the microbiologically caused nodulation of leguminous plants, which is important to allow these plants to get nitrogen from the atmosphere, is sometimes suppressed by low-level stresses, such as pesticides and acidity, and fertilizer nitrogen inhibits nodulation .

Plant ecologists emphasize the virtue of natural communities in which there are many different and dissimilar species. These communities are more resilient in the face of environmental change. Should there be a stress on an environment with a variety of different kinds of microorganisms, a species that is sensitive to the stress might be eliminated but could in turn be replaced by another species carrying out a similar function. In this way, the functions of the environment are not as markedly influenced by a particular deleterious change. The same generalizations may apply to microorganisms in soil. However, surprisingly little work has been done to determine the effects of agricultural technology on microbial diversity, except for studies designed to provide lists of taxonomic groups; although such lists are useful for the ecologist, they have not provided much helpful information on activities of microorganisms important to soil fertility or plant growth. The best evidence for a decline in species diversity as a consequence of modern agricultural technology comes from assessments of the response of microbial populations to fungicide treatment. Following such treatment, there is an abrupt fall in fungal diversity such that only a few species are dominant. These organisms may maintain their dominance for several weeks or for in excess of one year (1,2). The greater dominance may result from the resistance of the dominant organism to the original stress, but it also may be a consequence of the rapid recolonization of the soil by the dominant fungi after the chemical has been degraded or lost by volatilization or leaching.

Because of the differences in sensitivity, some species may be possible early indicators of environmental stress. The availability of an indicator organism is of value because tests of its response would serve as an early warning of a possible detrimental change. Investigations of pesticide effects have suggested that nitrification and the responsible organisms are good indicators because of their high sensitivity to toxic chemicals. The same microorganisms are inhibited by heavy metals, salts, declining aeration, moisture insufficiencies or excesses, etc. Nevertheless, apart from the few sensitive species indicated above, little attention has been given to the search for sensitive organisms or processes in soil, and possibly other microorganisms or processes would be better or would reflect harmful conditions that do not affect the organisms sensitive to the stresses that have so far been evaluated.

WHO IS MEASURING EFFECTS?

These measurements are being made in many areas of the world. Concern with the stresses of agricultural technology are not restricted to the United States, and scientists in western and eastern Europe, Canada, Japan, Australia and, to a lesser extent, in developing countries have been involved in the evaluations. The individuals performing the measurements in the United States are chiefly located at the state agricultural experiment stations and state colleges of agriculture. Such investigations have been proceeding for some

70 years, and the pace of activity continues; however, the type of stress that is of concern has varied appreciably with time. In addition, tests have also been conducted, but not as often, by the U. S. Department of Agriculture and, more recently and to a lesser extent, by the U. S. Environmental Protection Agency. Essentially no programs of this sort exist in private institutions, except for industries evaluating the potential impact of new pesticides on microbial activities. Industrial assessments of pesticide effects are prompted by regulations of the U. S. Environmental Protection Agency that require tests to be performed of a chemical that is being considered for pesticide use.

SPATIAL AND TEMPORAL ASPECTS OF TESTING

These tests have been conducted at either short or medium term intervals. In some instances, the tests involve data collection at hourly or even shorter time intervals, but some assessments involve daily or weekly measurements. In rare instances, the assessments are made for a full growing season. A critical deficiency in the assessments is the absence of data indicating possible long-term effects. This absence of information exists because few individuals have examined, on a regular basis, the microbiological changes that occur over long time periods; that is, whether the processes that are initially inhibited are suppressed for long periods of time or whether the microorganisms that are initially suppressed acclimate to the change so that the rates of their conversions are the same as before the introduction of the technology. Hence, an evaluation of the existing data base on the impact of agricultural technologies on soil microbiology and microbial functions must be tempered with the realization that information is scarce or totally lacking on the long-term consequences of most of the modifications in soil properties associated with modern agricultural technology.

Furthermore, the sampling procedure for assessing impacts has been almost chaotic. The samples have been taken at the whimsy of the investigator and relate only to his location, convenience and short-term concern. The approach has been to obtain soils that are located close to the investigator's laboratory and to assess impacts for only short time periods. There have been no systematic evaluations of the effects over large land areas with appropriate sampling procedures, and evaluations have not been performed to consider individual soil types, cropping procedures or meteorological circumstances important to U. S. agricultural and range land.

MICROBIAL RESPONSES TO SPECIFIC TECHNOLOGIES

Pesticides. Pesticides have been of particular interest as stress factors because they are deliberately selected for their toxicity to one or another group of organisms. Although these compounds are designed to control pest species, the extent of their selectivity for pests often is not great, and many other organisms are injured by the pest-control chemical. Among these non-target species that are harmed are microorganisms in soil.

Pesticides can be divided into functional classes based upon their role in controlling insects (insecticides), plant pathogenic fungi (fungicides and fumigants), weeds (herbicides), rodents (rodenticides) and nematodes (nematicides). Of these classes, tests to determine possible antimicrobial properties have been chiefly conducted on the first three, although some evaluations have been conducted on nematicides as well. The effects of hundreds of chemicals have been measured, and a variety of soils from many corners of the United States and elsewhere have been included in the trials. The application rates have ranged from those typically found under field conditions to levels far in excess of those used in agriculture. Because of the hundreds of chemicals representing dissimilar categories of organic molecules, only a few generalizations are possible on details of these effects.

Because pesticides are intrinsically toxic to one or another type of organism, inhibitions of microbial processes are not unexpected and have indeed been noted. These inhibitions are most common or most marked with fungicides and fumigants, and this is to be expected because these compounds are designed to be antimicrobial agents and because they are frequently applied at high rates to crops or soils. Inhibitions of a variety of microorganisms and microbial processes have been noted, and the suppression may remain for reasonably long periods after the chemical is first introduced into soil. The impact may be so great that the natural balance among the resident microbial populations in soil is upset so that new organisms, including plant disease agents, become prominent. Moreover, certain nutrient cycles that are regulated by microorganisms are inhibited by the fungicides and fumigants such that significant effects on plant growth and nutrition become evident. The lack of widespread concern with these antimicrobial agents is not because of their lack of toxicity but rather because they are not as widely used as are the other two major classes of pesticides.

Insecticides have received most attention in the past. These compounds may be applied directly to soil for the control of soil-borne insects, or they may reach the soil because of the drifting spray or when treated foliage or plant remains fall to the ground or are mixed with the soil as part of normal farm practices. The published information suggests that inhibition of one or another microbial processes or suppressions of individual populations of bacteria, fungi or actinomycetes may occur. On the other hand, the toxicity is generally not marked, and the beneficial effects of the insecticides in controlling insect pests have tended to argue for their use, although U. S. regulatory agencies have not acted on the basis of the possible long-term harm of insecticides to microbial processes. Nevertheless, few instances of major suppressions of microbial activities in the field have been noted, such that a change in policy in regard to their use does not appear to be warranted, at least in regard to considerations of short-term consequences.

Herbicides are designed to control the growth of higher plants; that is, those bearing seeds. Inasmuch as the amount of herbicide used per unit land area is small and the compounds are reasonably selective for higher plants, little or no inhibition by most of the herbicides has been noted. In some instances, herbicides have been found to alter microbial activities, but these changes probably are associated with the suppression of plant species that are sensitive to the pesticidal agent, the plant providing organic nutrients to the microorganisms around its roots; these effects do not seem to be of such a magnitude to warrant questioning the use of the particular chemical. An exception to the lack of toxicity is the inhibition of algae. Algae (which are lower microorganisms but also are plants; that is, they bear no seeds) are particularly sensitive to herbicides because they, like higher plants, carry out photosynthesis, and thus the physiology of these microorganisms is quite similar to that of higher plants. However, the role of algae in most soil processes is believed to be minimal, so that their inhibition is not deemed to be of great consequence (3-7).

The general consensus among soil microbiologists thus appears to be that a few pesticides have an effect on microbial processes in the short term, but the influence is not sufficiently marked to warrant cancellation of their registration and banning of the chemical. The continual assessment of the effects of new pesticides on microbial processes in response to current EPA regulations is worthwhile from such a short-term view. Moreover, many pesticides are degraded in soil or are lost by other mechanisms, and hence their toxicity diminishes with time. Nevertheless, evaluations of the long-term ecological consequences of pesticides to microbial activities have not been performed. It is possible that the widespread use of insecticides and herbicides and the local use of fungicides and fumigants do in fact have significant impacts on microbial processes, although this is unlikely because of the low chemical concentrations used, their selectivity for other species, their disappearance from soil by biodegradation or other mechanisms, and the possibility that microorganisms may acclimate to the stressed environment and repopulate the original treated soil. Nevertheless, the situation has not been assessed experimentally.

Fertilizers. Much information exists on the impact of synthetic chemical fertilizers on microorganisms and their activities in soil. These data come from tests performed in a large number of countries and using various fertilizer formulations, diverse cropping patterns and highly dissimilar soils. Because of this extensive research, it is possible to propose several generalizations on the short-term consequences.

Chemical fertilizers provide one or more of the nutrients essential for plant growth. The chief nutrient elements in fertilizers are nitrogen, phosphorus and potassium, but other elements may be included because the soils are deficient in that particular nutrient substance. Thus, iron, copper, molybdenum, zinc and other elements may be added to the fertilizer formulation or be applied separately to plants. The impacts of most of these elements on microbial populations and their functions have been investigated, but studies in the last 40 years have largely been conducted abroad, often in east European countries and sometimes in Asia. The topic has not been of great interest to U. S. agricultural scientists since the end of World War II, even though this was the start of the increase in the land area receiving fertilizers and in the rate of fertilizer application and new fertilizer formulations appeared.

The data from various tests---unfortunately using dissimilar application rates, modes of treatment and diverse soils---suggest that there may be a stimulation, an inhibition or no effect on microbial populations or their functions. Thus, one early study indicated that potassium and phosphorus stimulated microbial development and nitrogen enhanced the growth of bacteria and actinomycetes but not fungi. On the other hand, the same investigator noted that an acid-forming nitrogen fertilizer (such as an ammonium salt) promoted the development of fungi because it increased soil acidity, conditions that are favorable to fungi (8). Stimulation of the bacteria bringing about nitrification was also reported to result from the addition of potassium fertilizers or a mixture of fertilizers, the mixed fertilizer also increasing the number of bacteria able to convert organic nitrogen to the inorganic forms needed by plants (9). Other studies have verified that chemical fertilizers increase the numbers of total bacteria and those microorganisms which fix nitrogen and decompose cellulose and proteins (10). Conversely, other tests have indicated that certain fertilizers elements have little or no effect. For example, phosphorus and potassium was of little importance to bacteria in soil in one study (11). Similarly, the addition of nitrogen gave only slight increases in the quantity of organic matter decomposed and the amount of nitrate formed in soil, whether the nitrogen was added alone or in mixtures with phosphorus and potassium (12). Moreover, in some tests, fertilizer elements have been observed to be (a) stimulatory or without effect, depending upon the process, or (b) stimulatory, inhibitory or without effect, again depending on the organisms and processes concerned (13,14).

Anhydrous ammonia is a special case because of the high concentrations that are applied to a narrow region of the soil and its known toxicity. Studies of this fertilizer have shown that it is toxic to specific microbial processes for a period after its introduction into soil (15,16). However, the ammonia is converted in several days or weeks to the nontoxic product, nitrate, so that it is not certain whether the inhibition has any long-term significance.

Convincing data for a long-term detriment arising from the use of synthetic fertilizers thus do not exist. Although individual studies do in fact show inhibitions, these studies have not been continued to the extent that the suppressions have been shown to be long term or to reduce food production or microbial processes important to soil fertility.

Under certain circumstances, fertilizer elements have been added to soil in excessive amounts. These have resulted in a diminution in plant growth and in crop yield or quality. For example, copper has been added to certain soils as a nutrient element in such levels that it has injured citrus trees growing in the area. How such excessive levels affect microbial activity is largely unknown, but it is likely that the detrimental effect on plants is a good indication of a likely harmful influence on microorganisms as well.

Lime. Microorganisms convert ammonium salts used in fertilizers, anhydrous ammonia, urea and other sources of nitrogen to nitric acid. This process brings about the acidification of soil, which is frequently detrimental to microbial populations and processes. If the increase in acidity is unchecked, the rates of many reactions important for plant growth and the population sizes or functions of diverse microorganisms are reduced; for example, the microorganisms bringing about the formation of nitrate and the microbial conversion of nitrate to gases that are emitted from soil (denitrification) are inhibited dramatically, and not only the rate but the products of denitrification may be altered. The extremely important symbiosis between certain bacteria and leguminous plants which leads to increases in the nitrogen content of soil (the process being known as nitrogen fixation) is particularly sensitive to acidity, and it is frequently noted that legumes fare poorly and/or little nitrogen is fixed by this beneficial association when the acidity is appreciably increased. The rate of decomposition of organic matter and the regeneration of carbon dioxide that is critical in the atmosphere is also affected by acidification, but in this instance, the process may be either stimulated or inhibited by acidity (17,18).

Lime is added to soil to overcome the increases in acidity brought about by natural processes as well as by microbial action on nitrogen fertilizers. In light of the detriment observed because of the greater acidity in soil receiving acid-forming nitrogen fertilizers, it is not surprising that liming generally is beneficial as it counteracts the harm done by the acid. Evidence that microbial activity is enhanced by liming comes from tests of organic matter decomposition and nitrification in acid soils, both conversions being enhanced by the addition of lime (19,20). On the other hand, the conversion of organic nitrogen to the inorganic form is sometimes greater in the absence of lime, although liming may also enhance or have no effect on this transformation (21,22,23). Population sizes frequently increase following liming, and it is not uncommon for bacteria to become numerous, because these microorganisms are sensitive to acidity, and for fungal abundance to decrease because these microorganisms are promoted by the original acid conditions (24).

Assessment of the effects of acidification and of liming have been conducted for more than 50 years. The information is quite abundant and reasonably consistent from soil to soil and from year to year. Nevertheless, interest in acidification has recently risen because of the potential impact of acid precipitation on microbial activities. This renewed interest is justifiable, despite the early concern, because the acid is introduced directly at the top of the soil rather than being generated throughout the soil, as with nitrogen fertilizers. Moreover, many of the soils that are exposed to acid precipitation have different properties and support entirely different floras than the farmed soils tested heretofore; these are frequently soils that are already acid and that support trees rather than agricultural crops. Moreover, because these areas are not under intensive cultivation, they will not receive lime and they usually will not receive fertilizers so that any detrimental effect of the acid will not be reversed either by the corrective action of lime or by the addition of the nutrient element whose regeneration can no longer be effected, or be effected rapidly, by microbial activities (18).

Manure. The addition of animal manure to soil is an age-old practice. The benefits of this practice were realized in early man's husbandry of plants for crop production, and the process was encouraged as agricultural scientists realized that it was an excellent means to return nutrients to soil and to maintain soil structure. Microorganisms grow using the organic materials in the animal wastes as nutrients, and the extent of their response and the rate of their growth are dependent on the quantity and availability of organic matter in the excreta. As a consequence of this microbial activity, essentially all of the organic substances in the manure are destroyed and are converted to inorganic products, these including the carbon dioxide that is returned to the atmosphere and the other elements that are returned to soil to sustain plant growth. In addition, some relatively resistant organic materials are generated by microorganisms as they decompose the manure, and these resistant materials appear to enhance soil structure, which is important to root development and plant growth.

The effect of manure on microorganisms and microbial activities has been studied for more than 70 years. These studies have shown that the wastes promote microbial activity because the manure contains organic nutrients for microorganisms. Commonly, bacteria replicate rapidly and frequently reach very large populations. Individual physiological groups of microorganisms that perform specialized functions respond as well, especially those microorganisms that utilize the polysaccharides in the excreta. At the same time, microbial respiration increases dramatically as the resident populations use the oxygen to destroy the wastes and, in turn, emit carbon dioxide (25,26,27).

Recent years have witnessed a marked change in the use of land as a receiving body for animal wastes. The area of animal production units has been reduced, and enormous numbers of beef cattle, dairy cows, hogs and chickens are now confined in small land areas. The technology for animal production in confined areas improved rapidly, and farmers in ever growing numbers adopted the practice of putting in small land areas the animals that they had previously kept on large tracts of open land. However, this created a new problem, namely how to dispose of the vast amounts of animal wastes residing on a small parcel of land. A single farm may have hundreds to thousands of dairy cows, and several to tens of thousands of beef cattle may be confined in a feedlot with an area too small for convenient land spreading of the manure. A high percentage of the egg-laying hens and nearly all the broiler chickens in the United States are grown in confined areas, and the multitude of birds in a small site generate wastes equivalent, in some instances, to reasonably large cites.

The consequences of such confinement feeding has led to considerable research in recent years. The chief focus of interest in this research, however, was the potential for pollution resulting from the nitrogen in these wastes and the engineering problems associated with the disposal. Much less information was obtained on the influence of the wastes on soil microorganisms and processes. Because microbial decomposition is a major and often the sole means for destroying the animal wastes in feedlots or associated with confinement feeding, it is surprising that so little attention has been given to the microbiological processes associated with soil fertility. Nevertheless, it is clear from the research that the microorganisms that decompose manure or manure slurries use up the available oxygen in the soil, and this rapid depletion of oxygen has undesirable consequences. For example, ethylene is generated, and this gas is toxic to plants (28). Moreover, certain microbiological transformations of nitrogen are altered greatly, and new products or nitrogenous products in different amounts are generated (29). Furthermore, the decomposition of the manure causes changes in populations (30) and these alterations may be reflected in a modification in some of the transformations important to soil fertility. However, it is likely that the community of microorganisms will return to the conditions prevailing before the addition of animal manure, provided that the high rates of addition are terminated and that the large quantities of organic wastes are allowed to decompose.

Animal wastes often contain antimicrobial agents that are mixed with the animal feed to promote its growth. Some concern has been expressed about the possible detrimental effects of these antimicrobial agents once they enter the soil together with the manure in which they are voided from the animal's body. However, the existing body of information, which is quite limited, suggests that it is unlikely that these antimicrobial compounds will have a significant effect (31).

Plant Residues. Crop remains are regularly added to soil in order to return the nutrient elements that plants removed, improve soil structure and destroy the waste plant material. The influence of these plant remains on microbial processes and populations has been extensively explored. The effects vary enormously, depending on the particular plant material, the season of year during which it is returned to soil, the age of the plants, and the supply of inorganic nutrients needed by microorganisms. The plant additions may be from straw or they may be as green manures that are largely composed of actively growing plants. Typically, the numbers of bacteria and often fungi rise appreciably, and microbial respiration and the enzymatic activity of the resident populations also increase. After varying periods of time, the activity and populations reach a maximum and then decline, returning to the levels of activity and population composition of the original soil in periods varying from several weeks to many months. Some plant remains stimulate bacteria more than other microbial groups, but others primarily enhance the development of fungi. In some instances, individual microbial groups are suppressed, but the reasons for the suppression are not clear. Some agricultural scientists report no appreciable effect of crop residues on microbial populations, but the results of their studies are subject to question because the soil samples probably were examined after the peak of activity had been reached and the populations began to decline. The microbial attack on these plant remains may affect the severity of diseases of crops grown on that land, either increasing or decreasing disease severity (32-37).

Stubble mulching is a type of soil management that involves the maintenance of considerable quantitites of crop remains on the soil surface. These plant residues are derived from the preceding crop or crops. The purpose of stubble mulching is to minimize water and wind erosion, and it is a practice that has been of interest in the Great Plains, particularly where wheat is grown. The microbial effects of stubble mulching are related to the influence of the mulch on soil temperature and moisture and are dependent on the quantity of plant residues. Under the mulch, which is made up of the plant remains, the daily and seasonal fluctuations of temperature are not as marked as in bare land, and the moisture tends to be retained longer than in fields without mulch. This practice often increases the number of bacteria and fungi in the surface layer of soil as compared with ploughed soil. On the other hand, little difference in numbers of microorganisms is noted below the surface, and sometimes no microbiological influence of mulching is noted, even in the top few centimeters. Ultimately, the mulch is attacked by microorganisms and is thereby totally destroyed by these populations. Hence, the effect will ultimately disappear (38).

Agricultural Processing Wastes. Wastes from food, feed and wood processing are frequently disposed of by returning them to soil. In this way, a variety of organic materials derived from forest products, the processing of animals for meat, the manufacturing of dairy products, the canning of vegetables and fruits and the processing of material derived from grains are applied directly to land. These substances may be in a reasonably solid form or exist as waste waters. Little attention has been given to the impact of these processing wastes on microbial activities or populations. The problem is similar in many ways to that of animal manure in that the wastes contain a large quantity of organic matter which is degraded microbiologically. If the wastes are applied at not excessive rates and the oxygen level in the soil does not fall to zero, it is likely that the wastes will benefit microbial activity. On the other hand, many processing wastes give rise to considerable nitrate which, though having little direct impact on microbial activity, may yield a contaminant of the underground water supply (39,40,41).

Plowing and Other Tillage Operations. Plowing and other means of physically manipulating soil associated with tillage operations markedly affect the physical and chemical properties of the soil. The resulting modifications in temperature, moisture and physical properties of the soil dramatically influence microbial populations and their activities. This effect is commonly observed as an increase in microbial respiration following the physical disturbance. The microorganisms respond to the physical disturbance such that the soil's organic matter is more readily decomposed following mixing than in mechanically undisturbed land. Such an enhanced microbial growth at the expense of the soil's organic matter probably explains the frequently noted decline of organic matter levels in natural prairie and grassland soils that are first brought into cultivation. Although the physical mixing is beneficial to microorganisms, at least initially, the decline in organic matter level of such land may be detrimental to soil structure as well as affecting its moisture and aeration status and nutrient supplying power.

The promotion of microbial activities associated with plowing or other tillage operations has been shown in studies of several soil types and with diverse groups of microorganisms that carry out a variety of physiological reactions. The extent of the stimulation and which organisms are affected are determined by the nature of the plowing and cultivation procedures (42,43,44). The effect depends on the depth of cultivation, and it may result in the microbial formation of considerable quantities of inorganic nitrogen (45). The differential influence of subtilled versus plowed soil appears to be associated with the inversion of the plowed layer and the effect of the supply of available organic matter (46).

The significance of enhancement of microbial activity associated with cultivation and physical manipulation of soil is not clear. It is commonly believed that the decline in organic matter levels resulting from the stimulation of microorganisms is in fact detrimental rather than beneficial to soil fertility, but the stimulation of microorganisms has yet to be interpreted in terms of plant productivity or soil fertility.

The impact of crop rotations on the composition of the microflora has received extensive scrutiny. These studies have resulted in lists of genera of bacteria, fungi and other microorganisms that respond or are inhibited by particular rotations (47). In this instance, too, it is not clear what the population changes denote in terms of the properties of soil important to plant growth and soil fertility.

Many observations have been made of the impact of various other procedures associated with cultivation and soil management. For example, the maintenance of grass sod, the regular application of mulch and clean cultivation alter the rate of microbial respiration and have differential influences on various soil populations (48). Microbial populations also respond to the cultivation and cropping of peat soils (49). Similarly, the influence of deep versus shallow plowing (50), the continued application of animal manure for long periods (51) and the influence of drainage and plowing (52) have also been subject to scrutiny. Although the data base is thus large, the significance to soil productivity of nearly all these observations on microorganisms is totally unclear.

Irrigation. In many parts of the United States, irrigation is essential for crop production, and without supplemental water, plant growth would be negligible or totally lacking. In other areas, high crop yields can only be obtained when irrigation is practiced. Little attention has been given, however, to the direct effects of irrigation on microorganisms, although a few studies have been conducted (53,54). Irrigation appears to enhance microbial activities and increase the abundance of specific groups of bacteria, actinomycetes and fungi. Numerous studies have demonstrated that moisture often is a limiting factor to microbial metabolism, and such findings suggest that increasing water levels in areas where the soil moisture is too low for good plant growth will likely favor microbial transformations.

Irrigation may cause significant environmental deterioration, however. A not uncommon consequence of irrigation is salinization, the process of accumulation of salts in soils to such a degree that plant productivity, crop yield and soil fertility decline. Alkalinization, in which soils become saturated with sodium, may also occur as a result of irrigation. The salts that lead to salinization and alkalinization accumulate as water is lost from irrigated fields by evaporation and also from plants by transpiration, leaving the salts behind. In addition, capillary action results in upward movement of water from the underlying water table, and this may lead to accumulation of salts at the soil surface. In addition, salts in the irrigation water itself may result in salinization and alkalinization. The harm to plants and the reduction in soil permeability associated with salinization or alkalinization are well known. Soils damaged by such mechanisms are of little value for food production. The increasing salinization of the water supply and of the soil poses a real threat in many regions where irrigation is regularly practiced.

The effects of salts on microbial activities or populations in soil have been measured for at least 70 years, and the results of these studies are reasonably consistent. The microbial reactions that have been studied include nitrification, nitrogen fixation, nitrogen mineralization and microbial respiration, and the populations include the major categories of bacteria, actinomycetes and fungi. The effects depend on the particular salt that is applied and the soil under study. Moreover, occasionally some salts are without effect at modest concentrations. A stimulation is sometimes noted at somewhat higher salt concentrations, but these concentrations are still quite low. At levels that are often not excessive, however, certain salts suppress essentially all major microbial processes and major microbial groups important for biochemical functions in soil (55-60). The inhibitions occur because microbial processes are sensitive to increasing osmotic pressure, decreasing water activity and direct action of the ions from certain salts. Moreover, the changes in structure and chemical properties of soil may contribute to the inhibitions. The occasional stimulation is likely a consequence of the oligodynamic effect, which is discussed below.

Flooding and Draining. The flooding or draining of soils also has a marked impact on microbial activities. Considerable research has been done on the consequences of flooding, particularly as it relates to lowland rice production. The inhibition associated with flooding and the benefits arising from drainage have been observed with a number of microbial groups or processes (61-64).

Cropping. Cropping drastically influences microbial processes and specific populations. These effects are usually attributed to the excretions by plants of organic compounds through their roots or the presence of dying or dead tissues. These excretions or tissues serve as nutrients for microbial replication. The presence of such nutrients enhance the biochemical processes associated with nutrient turnover in soil, but sometimes the greater microbial activity leads to a diminution in the supply of inorganic plant nutrients because the subterranean microorganisms themselves use these nutrients and make them unavailable to plants. Moreover, the microbial populations may become enhanced to such a degree that they may stimulate or suppress plant pathogens. This field of inquiry has received an enormous amount of attention in recent years, particularly as it relates to the rhizosphere effect of crop species (3).

Deforestation. The clearing of forests may lead to changes in the water status of the area, increase water runoff along the soil surface, cause a fall in the water table and lead to drying of the land. In some regions, deforestation appears to have resulted in little or no serious depletion of soil fertility as the land was immediately put into use and a plant cover was maintained. Often, particularly in areas with steep slopes and high rainfall, deforestation leads to a marked deterioration in soil fertility.

A wealth of ecological literature exists on the microorganisms and microbial processes in forests and woodland areas. These studies have been conducted in part to understand the ecology of these environments and in part to characterize the microbial cycling of nutrients that are important to tree growth. The fungi and, to a lesser extent, the bacteria and bacterial processes of forests have been extensively investigated. Current concern with acid precipitation is focusing interest on certain consequences of man-made changes in forests. On the other hand, the microbiological effects of the clearing of forests have received little attention (65). It is likely that the altered moisture relationships, the loss of the litter layer from soil and the new plant communities following deforestation will greatly influence microbial processes, and it may be expected that the consequences of deforestation will be a reduction in microbial activities. Nevertheless, extrapolations are risky in the absence of a meaningful body of experimental information.

Heavy Metals. Heavy metals enter the soil in a variety of ways. Wastes from urban and industrial sites are applied to soil as a means for their disposal, and many of these wastes are rich in heavy metals. Heavy metals may be added together with lime or phosphate fertilizers, which may contain cadmium, copper, nickel, lead and zinc. The disposal of animal wastes and sludge from municipal sewage on land adds heavy metals to such an extent that crops growing in treated fields may be injured. Metals were present in many of the inorganic pest-control chemicals used before the advent of organic pesticides; lead, arsenic and copper were thus added liberally to many of the most productive soils of the United States. A few pesticides still contain copper and zinc, and some defoliants have arsenic, although the amounts added per acre are quite small.

The known toxicity of heavy metals to humans and other animals and their inhibition of plant growth under certain circumstances have prompted much research on heavy metals in soil. As a result, much is known about the toxicity of cadmium, zinc, copper, nickel, lead, mercury and other elements, both individually and in combination, to several of the major microbial processes in soil, including the decomposition of litter and soil organic matter, steps in the nitrogen cycle and enzymatic activities. Moreover, a variety of individual microbial groups have been tested. The data show that heavy metals are indeed inhibitory at low concentrations, the extent of the toxicity depending on the particularly heavy metal, its concentration, the soil type, soil pH and the individual microbial process or group (66-71).

MECHANISMS UNDERLYING CHANGES

Few of the studies of the impact of agricultural technologies have been designed to find explanations, although several investigators followed their original assessments with subsequent studies designed to account for the effects noted. In some instances, however, plausible mechanisms can be postulated based on other knowledge of the interaction of the stress condition with microbial populations in natural environments or laboratory conditions. Some of these hypotheses are based on a broad body of detailed information, whereas a few are only derived from general considerations of microbial physiology and toxicology.

Inasmuch as microorganisms are characteristically limited by the supply of energy for growth and their chief energy source is organic carbon, the beneficial effects of fertilizers (which usually are free of organic carbon) probably are not related to the fertilizer elements supplying the resident microflora with a nutrient source (3). It is likely that the beneficial effects of fertilizers result from their enhancement of plant growth, and the greater plant biomass favors microbial activity because of the excretions from their roots and the greater availability of crop residues that are subject to microbial decay. Inhibitory effects of fertilizers are probably related to the toxicity of salt components or ammonia in the fertilizer preparation or to the acidification arising from nitrogenous components, although inhibition of the nodulation of legumes that is important for nitrogen fixation and the suppression of nitrogen fixation itself by nitrogen fertilizers probably result from the well-known inhibition of these processes by inorganic nitrogen. The toxicities, though likely to occur with high rates of fertilizer application, are probably not of long term significance because the chemical dissolves and moves through the soil and the inhibition is relieved as microorganisms grow to replace those that have been inhibited or eliminated. There are few indications of long-term inhibitions associated with the utilization of synthetic chemical fertilizers, apart from the harm associated with increasing acidity if nitrogen fertilizers are used for long periods of time.

The stimulation arising from lime applications is likely a consequence of counteracting the inhibition from acidity. Many microorganisms present in soil, particularly among the bacteria, actinomycetes and algae, are notably sensitive to acidity, and these organisms are not functioning optimally, if at all, when the soil is quite acid. Lime overcomes the acidity and allows the microorganisms to grow, or grow better, so that the processes that carry out are more rapid following lime additions. Lime not only overcomes the effects of acidity but provides soil with carbon dioxide and calcium, but little evidence exists that increasing the carbon dioxide level or the calcium concentration is directly beneficial to microorganisms. The promotion of crop growth by liming will also increase the plant excretions and residues returned to the soil to sustain microbial proliferation.

The application of manure frequently is beneficial when added in small amounts and detrimental to many microbial populations when added in large amounts. The beneficial effect is likely related to the organic composition of the manure, which thereby provides energy sources for microbial proliferation and activity. These organisms not only replicate by using these organic substances but, in turn, they destroy the animal wastes. On the other hand, the harm arising from high concentrations of manure is probably related to the depletion of oxygen that microorganisms use in order to decompose the vast amount of organic material. In addition, manure contains a number of toxic constituents, and either the toxicants in the original wastes or those that are formed during the decomposition when the soil is poor in oxygen may suppress microbial processes. Such changes probably account for the beneficial or detrimental effects of a variety of other organic materials that are added at low or high concentrations, but the microbiological response may sometimes be related to improved water relationships or the minimization of extremes of temperature in soils that have organic matter additions.

The increase in activity following the mechanical mixing of soil associated with plowing or other tillage operations may be the result of one of several factors. The mixing of soil may make previously inaccessible organic matter available to microbial attack, and this organic matter will sustain greater populations and lead to enhanced microbial activity. In addition, soils that are mechanically mixed frequently have improved aeration, and the better aeration may enhance the growth of microorganisms that require oxygen. Soils deficient in oxygen support populations that act slowly, accumulate organic waste products and generate toxic substances. Mechanical mixing also alters the physical structure of soils and changes their moisture relationships, modifications that in turn influence microbial processes and populations.

The chief benefits of irrigation are to provide the water microorganisms need for growth and metabolism and to promote the growth of plants that sustain microorganisms with their excretions and dead tissues. Soils frequently have insufficient moisture for maximal microbial activity, water being an essential ingredient of their cells, so that the enhancement of activity may often simply be a consequence of providing water. Irrigation alters soil aeration, affects the movement of soluble organic and inorganic substances and alters temperature regimes, but the impact of these changes associated with irrigation have yet to be evaluated.

Salinization is generally harmful to microorganisms because of their sensitivity to increasing salt concentrations, but the effects of salinization may be related to the changes in the physical structure of soil. Microorganisms, except for those that are indigenous to salt-rich environments, do not tolerate high salt levels, and both their activity and cell structure are greatly affected as the salt level increases. Furthermore, because salts influence the growth of plants, microorganisms may receive less organic nutrients from root excretions or decaying materials that are left behind after harvest of the smaller amounts of plant mass.

Several reasons may be advanced to explain why flooding is frequently harmful and draining fields is often beneficial. The influence may be partly related to the aeration status of the soil, which is regulated by the amount of water present. The effects also may be associated with the microbial formation of toxins in poorly drained land and the absence of these substance from well-drained soils because the inhibitors are destroyed as quickly as they formed or because they are never synthesized when the field is adequately aerated.

Heavy metals are potent antimicrobial agents. Indeed, a classical laboratory method for destroying microorganisms and minimizing microbial contamination of equipment is to use salts of heavy metals, particularly mercury. Much information exists on the sensitivity of individual microbial populations to mercury, cadmium, lead, zinc, nickel, chromium and other metallic ions in laboratory conditions, and the inhibitions of microbial processes in soil probably simply reflect the direct toxicity of these heavy metals to the growth and metabolic activity of the indigenous populations.

Pesticides are developed and marketed because they are toxic agents. Although the pesticides are designed to be selective inhibitors so that they can be used for crop production, the degree of selectivity varies from chemical to chemical, and some are notoriously nonspecific whereas others act only on a range of closely related organisms. Because of the lesser or greater lack of selectivity in killing or inhibiting living organisms, many pesticides reduce microbial activities in soil. It is likely that these inhibitions reflect the inherent toxicity of the pesticide. Furthermore, some pesticides are modified by the activities of microorganisms in soil, and the modified chemical sometimes is more toxic than its precursor; hence, the inhibitory agent may not be the parent chemical in these instances but rather a substance produced from it.

Under laboratory conditions, microbial activity is often enhanced by low concentrations of inhibitors. This is the so-called oligodynamic effect. A number of the stimulations of microbial populations exposed to stress probably reflect this oligodynamic effect. This stimulation may be taken to indicate a positive influence, but it may simply be the first indication that higher concentrations or higher extents of stress may be detrimental. The oligodynamic effect has yet to be explained for individual populations in the laboratory no less for soil in the field.

ACCLIMATION TO STRESS

Some of the stresses of modern agricultural technology may have only a short term influence. The response to these acute stresses is expressed immediately, and it may be modest or dramatic. When placed under stress, however, the suppressed microorganisms may eventually acclimate to the stress circumstances, or the populations that are inhibited may be replaced by other microorganisms that are not only tolerant to the stress condition but function quite well in its presence. Such acclimations of microorganisms to a variety of stresses have been studied in either laboratory media containing individual microorganisms or in environments other than soil (72). Because such evaluations have not been conducted with microorganisms in soil, it is not possible to state whether microbial communities that are exposed, for example, to fertilizers or the detrimental effects of salinity or pesticides acclimate to these new conditions or are replaced by organisms that are not dramatically affected. The possibility of the acclimation of individual populations or components of the microbial community to the stress must be determined in order to evaluate whether one can extrapolate from short-term studies to assess the long-term effects of agricultural technology.

SOIL CHARACTERISTICS

A wide array of soils has been studied to determine the possible microbiological consequences of environmental change. These include representatives of the major classes and categories of agricultural and rangeland soils in the United States. The soils represent the major geographical and climatic zones of this country, and the assessments have been performed with soils that are from humid, semiarid and arid zones. Also included in the evaluations have been both mineral soils (that is, those that have large quantities of inorganic components) and organic soils (for example, peats and mucks). In addition, soils of varying degrees of salinity have been tested. Nevertheless, few generalizations exist that relate the extent of inhibition or stimulation of microorganisms to soil properties. Indications exist from laboratory studies that acidity, the presence of clay or organic colloids and the retention by soil of certain charged ions modify the effects of particular stresses, but generalizations that relate the impact of inhibitors to these properties under natural conditions have yet to be established on a firm footing.

The chief reason for the inability to generalize from knowledge of soil properties is that individual investigators have worked with one or another soil type, but few agricultural scientists have made a systematic assessment of the relationship of individual soil properties to the influence of particular stress conditions on microbial populations or activities. This lack of information on the importance of soil properties to possible effects is a major deterrent to attempts to generalize from the studies of the significance of agricultural stresses that have been conducted to date.

DATA AND ANALYSIS

Many hundreds and probably several thousand studies have been performed on the microbiological impacts of agricultural technology. Thus, the data base is enormous, and most, if not all, of the major technological innovations that might affect the microbiology of agricultural and rangeland soils have been evaluated. Therefore, the likely impact of a particular type of technological change or agricultural operation can be predicted, but only in qualitative terms. The same cannot be said to be true in quantitative terms. In addition, the studies have not been planned or conducted in a fashion to allow for extrapolation from the particular investigation to conditions prevailing in other soils or climatic areas, or where the vegetation is different. The investigators were seeking to establish the effects at their own particular experimental site, and they did not design their research programs to allow for generalizations that would be applicable to different areas or to dissimilar types of agricultural practices. Thus, generalizations cannot now be made on the quantitative responses of microbial populations in different soil types, dissimilar climatic regions and areas that have different types of vegetation.

Because few of the studies were carried out with a view to the long-term consequences, it is often difficult to use the existing data to predict what will likely happen in the future. The previous investigations were simply not designed to integrate studies over a longer time period.

The methodologies for assessing the consequences of technologies on microbial activity are usually well defined. Some exceptions exist because the importance to plant growth of certain microbial processes has not been adequately evaluated, and therefore little attention has been given to develop appropriate test procedures.

Essentially no models have been devised to predict how agricultural technologies will affect the aggregate of microbial activities that are important to crop production and rangeland management. In the past, tests were run on particular transformations, and the integration of these transformations in a fashion to allow for an assessment of the overall impact on the maintenance of soil fertility has yet to be attempted. Microorganisms and microbial processes interact with one another. Thus, interactions of microbial predators and their prey as well as parasites and their microbial hosts lead to feedback effects such that one population is regulated by another. Moreover, microorganisms interact nutritionally so that one population provides nutrients to another; these nutritional interdependencies result in synergistic effects whereby two populations acting together are more active than the sum of the two populations acting separately or they perform reactions that neither does alone.

Nevertheless, existing methodologies consider each transformation as a separate process, and the significance to plant growth of the synergistic, inhibitory or feedback effects have yet to be defined. In the absence of information of this sort, it is difficult to devise reasonable models of the impact of agricultural technology.

For these reasons, practical methods do not presently exist for scientific advisors, farmers and policy makers to predict the impact of existing technologies or the likely effect of alternative technologies on microbial relations important for plant production or soil fertility.

CONSEQUENCES OF DATA OR ANALYSIS INADEQUACIES

Government policies have not been based on an understanding of the rates, causes and consequences of microbiological changes in croplands and rangelands. On the other hand, the initiation of various policies and actions have not been constrained by the absence of meaningful generalizations. The probable reasons for pursuing policies and actions without a firm base of knowledge is the widespread belief in the enormous value of microbial processes in soil and the likely consequences of harm being done to these processes. Thus, statements are made and occasionally policies are followed that are predicated on the assumption that fertilizers will or will not have a devastating impact on microbial reactions important to soil fertility or that pesticides will or will not be detrimental to the continued use of land for food production or for range purposes. Similarly, statements are frequently made on the enormous value of organic materials being returned to the soil because of their benefit to microbial actions. Because policy makers, public interest groups and, on occasion, federal agencies have been largely acting with inadequate information, the impacts on microbial activities may sometimes be overdramatized, whereas in other instances, a significant problem may be wholly ignored. It is rare that the government, many agricultural scientists and agricultural extension specialists are acting on the basis of quantitative data that have been derived from well conducted field studies or from meaningful laboratory assessments.

The risks, costs or profits that farmers are incurring now or will incur in the future are thus entirely unknown. In light of the lack of an adequate data base and the shoddy understanding of the impacts of farmers' technological decisions, it is unwise to assume that there is either a cost to the farmer or a benefit. The extent of risk or whether indeed a risk exists in many cases is not clear. Indeed, questions of risks, costs or losses of profits have never been addressed by agricultural scientists in a fashion such that the data to be obtained from monitoring of impacts are useful in terms of farmers' operations.

Similarly, the benefits or losses to society and the long-term changes that may affect society's ability to feed itself in the future are wholly uncertain. Many scientists, governmental officials and members of the lay public have assumed that modern agricultural technology is bad for microbial activity and that what is bad for microorganisms is deleterious to soil fertility. Such views may be true, or some may be sheer fancy. Soil microbiologists believe that the activities of microorganisms are indeed critical for the continued use of land for food production, but the information now at hand does not provide scientists, no less society as a whole, with an adequate data base to determine the long-term significance of the acknowledged short-term changes in microbial populations and activities in croplands and rangelands.

Furthermore, the body of meaningful information is not increasing. The impact of agricultural technology on microorganisms is rarely being assessed at the present time, except for individual laboratory studies on a very few model soils for the purposes of pesticide registration. Not even these studies are adequately conducted to determine the long term impact of pesticides. Research on fertilizer effects on microbial activity, except for studies of fertilizer effects on nitrogen fixation, is not being conducted to a significant extent in the United States. The impact of heavy metals is receiving considerable attention, however, but the approach to these studies is not such that it will lead to the meaningful kinds of data that are necessary to determine whether the long-term productivity of soil resulting from microbial actions will be affected by heavy metal additions. Indeed, it may be said that the current approach to assessing impacts of agricultural technology on microbial activities in croplands and rangeland is providing some data but no conclusions and that the earlier research likewise has provided data, but that the conclusions are not particularly useful for policy makers, farmers, or land use planners. Society is being poorly served because it is being told that microbial processes are really important for the future use of soils, but yet there is no government policy to obtain a quantitative evaluation of whether these processes are indeed being affected.

CONCLUSIONS

Maximum use must be made of agricultural and range land, but at the same time it is essential that the same lands be treated in a manner that they will be usable for the same purpose in the foreseeable future.

Microorganisms are essential for soil fertility and the growth of plants. They synthesize plant nutrients that are not made otherwise in nature.

Nevertheless, the quantitative contributions of microbial processes to the fertility of soils and plant growth are almost totally unknown.

With few exceptions, information on which microbial processes or populations are likely to limit crop production or rangeland use is lacking.

Many studies have been conducted of the effects on microorganisms of fertilizers, lime, pesticides, the presence of plants, plant residues, salts, crop rotations, manure, plowing and other soil tillage operations. These studies have provided an understanding of the ecology of microorganisms and which microorganisms are or are not affected immediately upon the introduction of some management practice.

Despite the abundance of data, investigations of the effects of agricultural technology have focussed on few processes and few categories of populations.

Rarely are microbial responses correlated with what changes these populations bring about that are important for crop growth.

Differences in rates of microbial processes in soil as a function of season are well known, but little is known of the variation in rates from year to year or from site to site. This information is essential in attempts to assess the long-term impacts of agricultural technology on biological processes.

The significance of physical and chemical properties of soil in modifying the impact of agricultural technology on microorganisms and their processes is poorly defined. This information is critical to allow for generalizations from a testing or monitoring program.

A program to obtain these data does not exist.

Little is known about whether or how quickly microorganisms will revert to their original status and activity following the introduction or the continued use of some agricultural technology.

Convincing data do not exist to indicate what are the long-term effects of most aspects of modern agricultural technology on the microbial processes important to soil fertility, crop production, and plant growth.

RECOMMENDATIONS

Baseline information is needed on the rates of microbial processes in dissimilar soils in the absence of possible technological stresses. In obtaining this information, account must be taken of the variations from year to year and from site to site in particular types of soil.

The effect of physical and chemical properties of soil on the responsiveness of microorganisms to stress must be defined so that extrapolations from a few tests can be made to allow for regional or national impact assessments.

Determinations should be made of which microbial processes are significant or limiting in crop and rangelands and to environmental quality.

A continuing monitoring program is required to assess whether agricultural technology affects microbial processes important to the long-term maintenance of soil fertility and the productivity of cropland and rangeland. No such monitoring programs should be initiated until the requisite preliminary studies and tests have been conducted and suitable procedures have been devised.

ABSTRACT

Microbial processes in soil are essential for the growth of plants in croplands and rangelands. Many studies have shown that these processes are inhibited or stimulated by agricultural technologies. These investigations were usually performed to assess the short-term effects in one or a few soil types, and hence little information exists on the long-term impacts of agricultural technology or on the influence of soil properties on the response of soil microorganisms. To determine whether long-term effects are occurring, a program specifically designed for that purpose will have to be undertaken.

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Background Paper No. 2

IMPACTS OF TECHNOLOGIES ON RANGE PRODUCTIVITY IN THE MOUNTAIN, INTERMOUNTAIN AND PACIFIC NORTHWEST STATES

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Abstract

Rangeland forms the largest single classification of land in the Mountain, Intermountain and Pacific Northwest states. The area is characterized by low and erratic precipitation, saline deserts, and steep mountains. The native vegetation is low in natural productivity when compared with areas of higher precipitation.

In general, the rangelands of the West are producing less than half their potential. However, they are in the best condition that they have been in this century. Most of them had become heavily overgrazed within one or two decades after the introduction of domestic livestock. Range deterioration became widespread and most ranges were in poor condition by the turn of the century. In the last few decades ranges of the higher elevations have improved and some improvement has been noted in desert rangelands.

Rangelands are used for domestic livestock grazing, wildlife habitat, water production, recreation, mining, and military uses. These traditional uses are threatened by the widespread attitude that the western range is unimportant and can be used for missile sites, waste deposal, nuclear testing, etc.

There are a number of technologies available to improve the productivity of rangelands. The technologies are extremely site specific and should be perscribed under the direction of a well trained range manager. There are no technologies that can be applied to all sites. Technology is available to restore the ranges, but a national commitment is needed. Examination of the stated policies of agencies and the intent of Congress as outlined in the RPA, NFMA, Forest and Rangeland Extension

Act, Rangelands Improvement Act, etc. imply that there is a national commitment to improve rangelands. However, since few of the acts have been properly funded, one must question whether there is indeed a commitment to restore the rangelands.

Background Paper No.2

Impacts of Technologies on Range Productivity in the Mountain, Intermountain and Pacific Northwest States

INTRODUCTION

Rangeland is the largest single classification of land in the Mountain and Pacific states. Grazing by wildlife and domestic livestock is the most predominant use. For the purposes of this paper I have defined the Mountain and Pacific states' rangelands as those areas east of the Sierra Nevada and Cascade ranges and west of the Continental Divide, bounded on the north by the Canadian border and on the south by the Utah-Arizona border. The area contains virtually all of the states of Utah, Nevada, and Idaho; and roughly the western third of Montana, Wyoming, and Colorado; and the eastern third of Washington and Oregon. It includes all of the arid and semi-arid shrublands of the Great Basin, the wooded and grassed foothills of the mountains, the mountain vegetation of the west slope of the Rockies, the east slope of the Sierra Nevadas and the Cascades, and the entire vegetation on scattered mountains in the Intermountain and Great Basin area.

Almost all of the land within this broad geographical area can be considered rangelands. There are some major exceptions, those being the cities, roads, and narrow bands of cultivated land along the river bottoms and foothills. Small areas in the mountainous regions have dense forests and are managed for intensive forestry. Most of the land within these boundaries is in public ownership with percentages of public land as follows: Nevada, 86%; Utah, 66%; Idaho, 64%; Oregon, 52%; Wyoming, 48%; Colorado, 36%; Montana, 30%; and Washington, 29%. Those states lying wholly within the intermountain area, Nevada, Utah, and Idaho, all have two-thirds or more of their land in public ownership. In the remaining states those portions under discussion have similar percentages under federal or state management.

CLIMATE, SOILS, AND VEGETATION

The entire intermountain area is characterized by low and erratic precipitation. The Sierra-Nevadas and Cascades on the west and Rocky Mountains on the east form barriers to moisture movement and cause huge rain shadows within the area. Most of the precipitation comes as snow and may vary from as low as 4 inches in some of the salt deserts to as high as 40 or 50 inches at the tops of the mountains. Summer rains are not dependable, and most of the plant growth on which the productivity of the rangeland depends occurs as a result of moisture available for a short period of time in the spring.

The soils of the area range from highly saline playas and cold salt flats to steep, stony mountains, and contribute to a series of vegetation types that are ecologically best suited for rangeland use. In general, the broad valleys in the lower portion of the center of the basin are covered by low shrubs that have variously been described as salt desert shrubs or cold desert shrubs. Almost pure stands of shadscale (*Atriplex confertifolia*), Nuttall's saltbush (*Atriplex nuttallii*), winterfat (*Eurotia lanata*), greasewood (*Sarcobatus vermiculatus*), and big sagebrush (*Artemisia tridentata*) occur. In other areas these shrubs may occur in mixed stands with a half-dozen or so other desert shrubs intermixed. Grasses and herbaceous vegetation are usually scarce. The major amount of forage comes from the leaves and stems of the shrubs. This vegetation is usually high in protein but in some cases may be deficient in energy. A number of the native plants of the area, such as greasewood, or horsebrush, are poisonous. Some of the weedy invaders, such as halogeton (Halogeton glomeratus), are also poisonous. The area is used predominantly as winter range for sheep and cattle. Some year-round operations exist where spring-fall and summer ranges are available in the nearby mountains.

The lower elevations of the mountains and foothills throughout the area are usually covered by big sagebrush and grass, or by a combination of various low, shrubby, woody species. These areas receive slightly higher rainfall (10-20 in.) and the soils are less salty and somewhat deeper. It is these areas that provide the major spring and fall ranges for the livestock operations of the intermountain area. They also provide the major amount of forage for mule deer and elk in the winter. Much of this land is in private ownership. Many of the ranges have been improved or have the potential to be improved for livestock grazing, by removing the shrubby vegetation and planting grass. The major grasses that have been planted for this purpose are exotics, such as crested wheatgrass (Agropyron cristatum) or Russian wildrye (Elymus juncus). These introduced species appear to be easier to establish and maintain themselves better over a long period than do the closely-related native bunch grasses. The foothill lands are in great demand, since spring-fall ranges are in short supply and are used heavily by wildlife and livestock.

The mountains of the area support complex vegetation with a number of plant communities, varying from low shrub on the foothills to subalpine and alpine areas in the higher mountains. In general, they vary with the amount of moisture and elevation and occur in the continuum of plant communities from the lowest to highest elevation as follows: low shrubs such as sagebrush, pinyon-juniper, Ponderosa pine, aspen or lodgepole pine, spruce-fir, subalpine forest, and alpine.

One or more of these communities may be absent on some mountains, and the plant communities may be reversed on others, depending upon the local micro-climatic conditions. Ponderosa pine occurs in the southern part of the range, and in the northern ranges of Washington, Oregon, and Idaho, but is essentially absent in the center of the intermountain area.

The lower elevations in the sagebrush, pinyon-juniper, and Ponderosa pine areas may be used for spring or fall range. The higher elevation ranges are used almost exclusively for summer range. It is also in these high areas that most of the water is produced for the entire region and these scenic areas form the nation's prime recreation land. They are used for hunting, fishing, camping, hiking, back-packing, etc., in the summer and for skiing, snowmobiling, and other winter sports in the winter. Some of the higher elevations ranges in Ponderosa pine, aspen, lodgepole, spruce-fir, and subalpine areas have commercially marketable timber. The better stands have been classified as intensive forest lands and are managed for timber production. Those scattered, poor-quality stands are usually considered multiple-use rangelands and are used for a number of uses, but some timber may be harvested. The vegetation and plant communities will not be described in detail in this paper. Their descriptions occur in textbooks such as Stoddart, Smith and Box (1975) and in recent reports such as USDA (1980).

HISTORY OF USE

The rangelands of the intermountain and Pacific states were settled late in U.S. history. For the most part, they have been occupied less than 150 years. People from the midwest and eastern states were not readily attracted to the intermountain area. The discovery of gold in California caused many people to cross the area but few stayed. Their reports, coupled with those from mountain men who had been engaged in the fur trading business, created considerable interest in many of the local valleys.

Settlement patterns in general followed the mining industry. Where gold or other precious metals were discovered a settlement occurred. Livestock and other support industries soon followed, and towns and permanent villages were established. A major exception to the general settlement pattern of the intermountain region is the state of Utah where religious refugees were looking for a place to establish a new home.

The general pattern of settlement of this large area could be summarized as follows: something, usually gold or precious metals, attracted a few adventurous people. A support industry followed and the arable land was quickly settled and occupied. Since little of the land in this area can be farmed without irrigation, water was quickly diverted from the streams and claims filed for this most valuable resource. The forests were soon cut over or high graded, first for building materials and then for fuel wood. In addition, better timbers were cut by the mining industry, which generally selected the best or most easily accessible logs for mine props and construction timber. Some of the early smelters operated on wood or charcoal, and the forest provided fuel for those. Pictures of the early settlements all show rather open, cut-over areas around the major cities and towns. Some of these mining areas became ghost towns and others developed into major trade centers, such as Boise, Reno, and Salt Lake City.

Rangeland use followed a very similar pattern to that of general settlement. As a new town developed, a few livestock would be brought in. Herds would build up over the years until the area became overgrazed. Once a drought or a hard winter occurred, there would be a large die-off of livestock. This pattern appears to have been repeated over and over again, and all of the records that I have examined report that ranges were severely overgrazed within two or three decades after their settlement. Records of this overgrazing early in the history of the western range can be found in almost every state. A typical exampled occurred in the state of Utah. The first settlers came into the Salt Lake Valley in 1847. Howard Clegg, analyzing the records of the Mormon Church in Grantsville, Utah, found the following quotation from the Deseret News dated September 25, 1879:

> The wells are nearly all dried up and have to be dug deeper. At the present time the prospects for next year is a gloomy one for the farmers, and in fact, all, for when the farmer is affected, all feel the effects. The stock raisers here are all preparing to drive their stock to where there is something to eat. This country, which is one of the best ranges for stock in the Territory, is now among the poorest; the myriads of sheep that have been herded here for the past few years, have almost destroyed our range (Clegg, 1976).

Similar reports can be found time and time again and related to specific locations throughout the intermountain area.

DEVELOPMENT OF RANGE MANAGEMENT

The management of rangelands on a scientific basis is relatively new. It is an American science that began about the turn of the century. Prior to that time concern was already being expressed over the deteriorating condition of the western rangelands, and the Division of Agrostology or the U.S. Division of Economic Botany did several surveys and discussed the need for scientific management of rangelands. Those early surveys showed that the ranges were heavily overgrazed. The first federal research was conducted in Texas in the 1890's by H. L. Bentley, but scientific management of rangelands began with the establishment of the Forest Service in 1905. During the period of 1910-1920 the first courses in range management were taught. It is significant that all of the early courses, curricula, and research work developed in the intermounatin and Pacific states. Among the first schools to teach range management were Utah State, Montana State, and the University of Idaho. The first standardized procedure for classifying rangelands and rating then into condition classes was developed by James L. Jardine in 1911 (Sampson, 1923). This procedure with various modifications was used by most of the government agencies until the mid-1930's, when agencies met and developed a standard interagency range survey technique (Standing, 1933).

Descriptions of the evolution of the science of range management are found in a number of standardized texts--Sampson, 1923; Stoddart and Smith, 1935, 1955; Clawson, 1950; Heady, 1975; Stoddart, Smith & Box, 1975.

One important concept in range management that developed through the years is the estimating of productivity through a process known as range sites and condition classification. A number of different systems have been devised to estimate productivity; these will be discussed later. The basic premise behind them all is that there exists a relationship between the composition and makeup of the plant community and its general health. By mapping the sites where soils occur that are capable of producing similar vegetation, one can then measure various parameters of plant communities and get some general estimate of productivity. Most of the modern techniques relate this estimate of productivity to ecological succession stages. The early or weedy stages are considered less productive than the climax stages. This attempt to relate the plant community to its potential or climax condition offers a great deal of promise for allowing one to manage for multiple uses. However, if productivity is measured only for a single use, such as grazing, wildlife habitat, watershed, etc., some of the earlier seral stages may be as productive, if not more productive, than the climax site.

RANGE PRODUCTIVITY

The first attempts to estimate productivity were made by explorers, mountain men, and others who passed through the Intermountain West. Accounts of seas of grass belly-deep to a horse are common in the writings of those who first viewed the area. It is also true that other entries in those same journals may describe barren wastelands with little or no forage available for days.

In general, people tended to overestimate the carrying capacity, and the optimistic reports of unlimited forage led very early to the overstocking of the ranges. Unfortunately, there are no detailed descriptions of botanical composition, soils, or other measurements by by which one can get a true picture of range productivity at the time of settlement. The first actual, on-the-ground surveys were accomplished in the late 1890's and early 1900's. These range surveys in general found the West to be depleted of forage and in poor condition. Major reports exist from the various areas by Smith (1895) in the southwest, Colville (1899) in the northwest, Kennedy and Doten (1901) in the Great Basin, and Nelson (1898) in the Red Desert of Wyoming. All of these reports indicate that uncontrolled free grazing had severely depleted the range. Most of the rangelands of the western United States were overgrazed in the first two or three decades following settlement. The depleted conditions people deplore today are largely a result of historical use. The first system for controlling grazing appears to have been on Indian land in 1891; but by 1894 the regulations were being formulated for controlling grazing on forest reserves (Stoddart, 1950).

A general concern over the condition of the western range developed in the mid-1930's. This led to the first nationwide assessment of range conditions with Senate Document 199, 74th Congress, Second Session, entitled The Western Range. The document included a summary of western range use at the time of the Great Depression and made a preliminary assessment of the condition of the ranges. The survey showed that 57.5% of the public range was in poor condition (severe or extreme depletion) (Table 1). Another 26.4% was in fair condition, leaving less than 20% of the rangelands in good or excellent condition. The report showed the Forest Service lands were in the best condition of all public lands, with almost half, or 45.5%, in good condition. The lands under control of the Public Domain, later to become the BLM, were the worst condition, with only 1.5% in good condition. This difference in condition between

Table 1. Percent depletion of rangelands by ownership in 1935 (from U.S. Senate Document 199, 1936).

Land Control	Percent by Depletion Class			
	Moderate Depletion	Material Depletion	Severe Depletion	Extreme Depletion
Federal				
National Forests	45.5	40.0	12.0	1.5
Indian Lands	6.6	35.8	54.0	3.6
Public Domain	1.5	14.3	47.9	36.3
Other Federal	2.0	21.2	50.1	26.7
All Federal	16.1	26.4	38.1	19.4
State and County	7.1	47.4	37.0	8.7
Private	11.7	36.9	36.4	15.0

the lands managed by the two agencies can be demonstrated by examining the trends in range condition between 1905 and 1935 (Table 2). Over three-fourths of the National Forest lands had improved during the 30-year period and only 5% had declined. On the Public Domain only 2% had improved and 93% had declined. The improved condition on forest lands showed the value of management and demonstrated quite early that the application of technology could improve rangelands. Ranges in the public domain, which were still considered "free" and subjected to excessive use were continuing to deteriorate.

The 1935 Senate Document is significant in the management of rangelands, marking the approximate time in which the public domain was brought under scientific management. The Taylor Grazing Act of 1934 created a mechanism by which use of the public domain could be controlled. Unfortunately, full implementation of the Grazing Service was delayed by World War II. It was not until the late 40's that public land policies on grazing were implemented.

The next national range survey was made by the Public Land Law Review Commission (Pacific Consultants, 1968). The results of this survey are shown in Table 3. The analysis by Pacific Consultants marked the first national inventory of range condition since the publication of The Western Range in 1936. Unfortunately, the data in the 1966 survey cannot be compared directly with that of the 1936 study. The earlier study did not report the status of the range in range condition classes as are now understood in range management. The art and science of range management had advanced considerably during the 30 years between the studies; indeed, the entire concept of range condition was developed

Table 2. Trends in range forage depletion from 1905-1935 (after Box, Dwyer, and Wagner, 1977).

Land Control	Percent of Land by Trend Class		
	Improved	Declined	Unchanged
National Forests	77	5	18
Indian Lands	10	75	15
Public Domain	2	93	5
Other Federal	7	81	12
State and County	7	88	5
Private	10	85	5

Table 3. Percentage of land in three condition classes in 1966 by federal agency.*

Land Control	Percent by Condition Class		
	Good or Excellent	Fair	Poor
USDA Forest Service	20	44	36
BLM	19	52	29
National Park Service	45	28	27
Fish & Wildlife Service	41	46	13
Bureau of Reclamation	15	35	50
Department of Defense	28	60	22

* Adapted from Pacific Consultants (1968). Data are rounded to give relative percentages in three major classes. Interpretation is that of Box, Dwyer, and Wagner, 1977.

during the intervening years. An attempt to relate the 1966 and 1936 studies has been made by Box, Dwyer, and Wagner (1977). They concluded that the assumption in the 1966 report, that three-fourths of the western range was producing at half its potential, is a fair assessment. They stated that there had been some range improvement made since the 1936 study, most of the increase in productivity apparently occurring on the public domain. In 1936 the estimated percentage of land in good condition was only 1.5% on the public domain (U.S. Senate Document 199, 1936). In 1966 18.9% of the BLM lands were in good to excellent condition (Pacific Consultants, 1968).

In the early 1970's two government reports estimated range conditions throughout the country. These were the USDA's 1971 Inventory of Soil and Conservation Needs and the USDA's Forest Service 1972 publication entitled "The Forest-Range Environmental Study." Apparently data from both of these studies were the same as used earlier by Pacific Consultants (1968). In addition, range conditions throughout the country were reported by eco groups rather than by agencies or states, making direct comparisons with earlier reports difficult.

In the mid- to late 1970's a number of individual state reports were issued by BLM state offices (Bureau of Land Management, 1974, 1975a, 1975b, 1975c). One of the major ones was a 1974 in-house publication by the BLM state office in Nevada entitled "Effects of Livestock Grazing on Wildlife, Watershed, Recreation, and Other Resource Values in Nevada" (BLM, 1974). The report was a highly critical self-study of BLM's activities in the state of Nevada. It showed that the BLM was understaffed in all districts of the state and that the rangelands were undermanaged. The report was originally intended as an in-house study;

however, it become the catalyst for environmentalists and land users to attack BLM management policies and led to an overall criticism of rangeland management throughout the western United States. In addition to the state reports spawned by the Nevada reports, the BLM developed a report (BLM, 1975d) for the Senate Committee on Appropriations. This report showed that about 17% of the land was in good or excellent condition and that about one third of the land was in poor or bad condition. The reported trend was 19% improving, 68% static, and 16% declining.

The Resources Planning Act of 1974 required the Secretary of Agriculture to periodically assess the national situation relating to forest and range resources of all ownerships, and to make recommendations regarding those forest and rangeland resources managed by the United States. The first assessment was released in 1976 (USDA, 1976 a, b, c). This assessment left much to be desired, since few new data were added. The information for range condition and amount of land by ecosystem apparently was taken from the FRES report. In addition, many of the data for the FRES report came from older reports or broad estimates made by agencies. Box, Dwyer, and Wagner (1977) concluded that the RPA assessment was a good first attempt at assembling information already on the shelf but added little new data.

The changes in range condition between settlement and 1977 have been summarized by Box, Dwyer, and Wagner (1977) as follows:

> Techniques for measuring range condition are imprecise at best, even today. Estimates through the years have been developed for many purposes and with variable techniques. Even though the range has been viewed through different eyes and measured against new technology at each major assessment, we believe that some sound generalizations can be made.

First, it is our opinion that virtually all the western range had been grazed exploitatively in the 1800's and that by the beginning of the twentieth century only those lands poorly watered or with some other natural protection could be considered in good condition. The early major range deterioration in North America occurred within three or four decades after the arrival of domestic livestock at a given point. For most of the West this was between 1850 and 1900.

Between 1905 and 1935, National Forest Rangelands improved but conditions of other ranges continued to decline. It was during this period that grazing was brought under control on the National Forest and range management as a science began to emerge. Some range management publications appeared in the 1910-1930 period. The first range courses were taught at colleges, and range research projects emerged (Stoddart, Smith, and Box, 1975). It appears that isolated improvement was made on private and Indian lands during this time, probably only in restricted areas where the emerging art of range management was taught and/or practiced.

In the next 30-year period between 1936 and 1966 we conclude that federal ranges have improved some. Although there appears to be little or no change in the percent of good or excellent range, the amount of range considered to be in poor or bad condition is estimated to have declined from 58% in 1936 to 33% in 1966. At the same time, the amount of fair condition range increased from 26% to 49%. This shift from poor to fair condition was more pronounced on the public lands. We feel that the reported overall improvement of the public domain ranges will be small because they are extremely depleted by excessive free range at the beginning of the period, and the arid nature of most of the public ranges does not permit them to respond quickly to management. An improvement of one condition class in thirty years can be considered a successful response to management.

We seriously doubt that there is any real difference in the condition represented by thefigures reported in 1961, 1966, and 1972. This information is probably all from the same data base and even though there was updating between surveys, the methods reported varied, and any real differences in the range could be masked by the way in which the data are collected. Our personal observations are that foothill and mountain vegetation improved during the decade of the 1960's but that few desert ranges changed enough to be obvious without intensive sampling. Unfortunately, few detailed condition studies have been made on desert ranges since 1966.

The most recent assessment of forest and range conditions in the United State is included in the 1980 RPA assessment (USDA 1980a, 1980b). The condition and productivity of the ranges and the Intermountain and Pacific Northwest area are included in Tables 2.3, 2.4, 2.5, 2.6, and 2.8 of the RPA assessment (USDA, 1980a). These will not be repeated in this current paper but by reference are made part of the data for the most current estimate of productivity.

While current studies indicate that the range continues to improve, I believe that the ranges of the Intermountain West are still producing at less than half their potential as far as livestock grazing is concerned.

MAJOR USES OF THE MOUNTAIN, INTERMOUNTAIN AND PACIFIC NORTHWEST RANGES

The grazing of domestic livestock is generally considered to be the primary use of rangelands, but many other uses occur. The potential for multiple-use is particularly high on the public rangelands of the mountain and intermountain states.

Rangelands of the West are low-producing when compared to land of the more humid areas. Therefore, they are generally regarded as wastelands that can be used for purposes that would not be tolerated in the more densely-populated areas. Two uses that are often relegated to the arid rangelands are military bases and waste disposal areas.

Traditionally, our major bombing ranges have been located in the desert regions of the intermountain rangelands. Literally hundreds of square miles have been designated for bombing or missile ranges. Several western states such as Nevada, Washington, and Idaho, have major nuclear test facilities. The amount of actual space taken by these sites may be relatively small; however, the fallout and health hazard may extend over large areas. Many of the ranch families in southern Utah claim to have suffered extensive health problems and deaths following nuclear testing.

There are a number of recorded cases where losses have occurred of large herds or flocks of livestock due to poisonous gas and other military activities. The use of rangelands for bombing ranges, nuclear test sites, nerve gas tests, and gas storage have resulted in loss of land, loss of livestock, and human health hazards.

Several proposed military or waste disposal projects in the West could vastly disrupt the traditional uses of land. Purportedly the largest public works project in history, the land-based MX missile system, is being considered for Utah and Nevada. If the projected 4,600 missile silos are located in these two states, this project alone will effectively dominate all other uses in every major desert valley in western and southwestern Utah and eastern Nevada. Add to this proposals to use the western ranges for the storage of gas weapons, for the testing of missiles, and for nuclear disposal areas, and traditional multiple use of the intermountain ranges appears bleak.

The productivity of the ranges of the mountain, intermountain, and Pacific northwest may be severely changed during the next decade by military use alone. In my estimation, the potential military use could be the most damaging of any single use in the western United States. Most other uses are compatible, so that the land could continue to be managed for multiple uses. However, once land is withdrawn for the military and becomes part of our vast national security complex, it is doubtful if other uses can be made simultaneously on that land. It may be logical, and it may be in the country's self-interest, to locate these single-use, land-consuming activities in the low-populated areas. However, the decision to make these sites national sacrifice areas should be made only after Congress is made fully aware of the effect this will have on other uses of the land.

Almost all of the ranges in the Mountain and Pacific Northwest states are used for recreation of one sort or another. Hunting is practiced anywhere wild birds or animals occur. Wildlife viewing, fishing, camping, picnicking, and other dispersed recreation activities are common throughout the area. While activities are generally concentrated around water or in the more scenic areas, even the most remote areas receive some use, particularly during the big-game hunting seasons.

These dispersed recreation activities are not particularly damaging to the land if properly damaged. Conflict may occur if recreationists harrass livestock, start erosion patterns on roads or trails, etc., but, in general, dispersed recreation is compatible with other uses. A major exception may be in the use of motor vehicles. Damage by off-road vehicles appears to be a major problem on almost every range district in the intermountain area. The amount of use and the extent of damage depends on the proximity to heavy population centers and erodibility of the land. However, there are few places in the West that are totally immune to off-road vehicle damage.

One of the most controversial areas in the outdoor recreation field is in the designation of wilderness areas. Even though the Wilderness Acts provide for continued grazing and other uses within wilderness, the concensus of users is that once land is designated as wilderness more and more restrictions are put on its use. Therefore, such traditional users as grazers and miners resist the designation of additional wilderness, while preservation groups work to get additional areas designated.

Recent clarifying regulations by the Forest Service on grazing in wilderness may help alleviate some of the tension between wilderness and nonwilderness users, but the problem of wilderness designation will continue to be a major emotional item among users for some time to come.

Water is perhaps the single most important product from the high-elevation ranges of the mountain and intermountain areas. It is on these high elevation ranges that the water occurs that is needed for the culinary, industrial, and agricultural purposes of the population centers in the intermountain region. The yield of runoff water is less important on low-elevation ranges; however, here the effective penetration, storage, and use of the limited amount of water that falls is a major item to consider in the management of those ranges.

Although there are timber producing areas in the intermountain and Pacific Northwest states, most of those are not on the lands generally considered rangelands. Timber production may be locally important at high elevations, but because of the lack of high-quality saw timber it is relatively unimportant for the production of wood or wood products.

The oil and gas shortage and increased prices have led many people to begin using wood for space heating in their houses. This rather recent and dramatic change has caused a major increase in the value of the wood products from these low-quality forests and forest-range areas. For instance, in the past the pinyon and juniper woodlands were considered primarily as rangelands. Some limited sales of Christmas trees and fence posts occurred from these lands, but the woody vegetation was a noxious pest, to be removed through chaining, burning, or other brush control techniques.

In recent sales in Colorado, Nevada, and Arizona of pinyon timber firewood brought as much as $18-$24 per cord on the stump. Retail prices may reach $80-$100 a cord. Prices such as this make wood a valuable product that is economically competitive with livestock grazing, wildlife, and other uses. This increased value of fuel wood also opens up new opportunities for type conversion or vegetation control in those wooded areas. Instead of removing the vegetation with bulldozers, it may be more practical to design fuel-wood sales in such a way that wildlife habitat and domestic livestock grazing can be enhanced.

The development of the coal, uranium, and other mining throughout the West has also created a new market for mine props and other wood products that may be harvested from what was previously considered poor quality woods of the western rangelands. Where timber was considered non-economical on much rangeland less than a decade ago, today's increased demand for fuel wood and mine props make possible an effective economic use for these low-value woodlands. Even where the value of wood is only marginally economical as far as harvest is concerned, it may be a factor in providing incentive for changing the vegetation to a type that is more conducive to game or livestock.

Big game hunting is traditional in all western states, and the ranges provide the feed and shelter for the deer, elk, and other big game animals. Mule deer numbers have declined throughout the West for the last several years, to the considerable concern of both state Game and Fish Departments and sportsmen. However, at the same time that mule deer numbers were declining, increases in elk have been reported in most states. Wagner (1978) and others have speculated that this alteration is caused by a change in vegetation from shrubby to grassy ranges. This observation would further substantiate the statement made earlier that the ranges have indeed improved and developed more pristine-like conditions during the last two decades.

The allocation of forage for wildlife and game animals has been a controversial issue in most of the districts throughout the West. The amount of competition between wildlife and domestic animals varies according to site and specific conditions. In general, there is adequate summer range, and in most cases adequate winter range, for livestock. However, it happens in much of the West that those areas that are spring-fall range for livestock are also winter ranges for big-game animals. It is in these areas that the most extreme competition appears to manifest itself. Local instances of competition may exist on all types of ranges throughout this broad intermountain area, but appear to be the most severe on spring-fall ranges for cattle and winter ranges for game animals. Recent work by Urness and others has shown that properly managed livestock grazing may enhance the amount of forage available for wild animals, and actually improve wildlife habitat. Specific habitat requirements, such as sagegrouse booming grounds and elk calving grounds, are important. In vegetation type conversions or other range improvement practices that may disrupt these specific habitat requirements they should be considered as a constraint.

Other controverisal segments of the wild or free-roaming animal populations on western ranges include predators and wild horses and burros. Livestock lost to predators may be great in some localized areas and almost non-existent in others. Where their populations are not adequately controlled herds of wild horses or burros may be locally damaging to rangelands throughout the intermountain area.

The great diversity in the intermountain area, combined with its geologic history, has led to a high number of endemic species of both plants and animals in isolated mountain ranges and valleys. Therefore, a large number of rare and endangered species may occur at almost any location. Many of these may not be known until intensive surveys have been made.

Oil and mineral development is of increasing importance throughout the ranges of the West. The overthrust belt of the Rocky Mountains, running from the Canadian border through most of the western states into Arizona, is one of the most actively-explored structures in the United States. Almost every western state has huge supplies of coal. Oil shale occurs under many of the rangelands of Colorado, Utah, and Wyoming. Tar sands occur in Utah, and hard rock minerals are found in almost every western state.

Our national desire for energy, the increasing price of gold and silver, and other economic changes will make the western rangelands highly vulnerable to increased activity of the mining sector. With this increased activity there will be a greater need to rehabilitate those areas that are disturbed by oil and gas exploration, mining, etc. (NAS; 1974; Schuller and Sutton, 1978). The direct disturbance of the sites caused by mining may be fairly minor when compared to the impact of people and to the off-site effects of mining.

The projected increase in human population in the intermountain and mountain states, due primarily to increased mining and military activities, is staggering. New towns will have to be built, transportation systems developed. More roads will be built and access to the rangelands will become much easier. These increased numbers of people will affect every use discussed above. Game herds will be hunted more heavily, livestock harrassed, recreation sites damaged, Indian artifacts destroyed, historical sites vandalized, water diverted from agricultural to mining and industrial uses, etc. The rangelands of these intermountain states, which only a few decades ago were primarily livestock-producing areas for a low human population, will rapidly become the playground and the waste-disposal area for large number of people engaged in military or mining activities, industrial development, etc. However, these same rangelands will be called upon to produce the traditional red meat and big game herds for which these new people and old ones alike will depend.

RELATIONSHIPS BETWEEN TECHNOLOGIES AND PRODUCTIVITY

The poor condition of most of the western rangelands is a result either of the improper application of technology, the misapplication of a technology, or the failure to apply principles proven in the past. For instance, most of the rangeland deteriorated very quickly after the first settlement due to severe over-grazing. The over-grazing was caused by an overly-optimistic evaluation of the carrying capacity, which resulted in placing more animals on the range than it could sustain in perpetuity. Current range managers have inherited a system that was a direct result of misapplication of grazing. The proper application of grazing may be one of the major technologies for the recovery of those same rangelands.

Another technology that has been madly misapplied is that of the use of fire. Most rangelands evolved under a regime of periodic burning of the rangelands. The rather strict control of fire has led to an increase in woody vegetation in much of the West. Other examples, such as over-cutting of forests without regeneration, could be used as examples of misapplication of technology, which lowers the productivity of the range.

Many times a technology was available, such as controlling animal numbers, but was not applied because government regulations or laws would not permit it. For instance, before enactment of the Taylor Grazing Act there was no legal mechanism for regulating grazing on most of the public domain. Many of the states in the intermountain area have statutes requiring that the state lands be managed for maximum income for the schools. This management for maximum income in the short run may lead to the misapplication of technologies that would enhance productivities over a longer period of time.

In times of national stress such as World War I and World War II animal numbers were allowed to build up, even though the technology for controlling them was available. These and many other examples could be cited where either the misapplication or failure to apply technology has resulted in lower productivity of the range.

One of the options available to the land manager is simply to do nothing. Unless some positive action is taken to apply the technologies available, those lands that are now improving may continue to improve; however, the lands that are in static or declining condition will probably continue to decline, even if the same stocking rates are maintained. If the do-nothing technology also includes doing nothing to control increasing numbers of big game animals, wild horses and burros, the ranges in the intermountain and Pacific northwest states would probably decline over a period of decades. These arid regions are slow to heal themselves, and unless grazing pressure is removed those areas that are now in poor condition with a declining trend would continue to decline. As the herds of feral and wild animals increase, those areas that are now in upward trend or in good condition would also probably decline. In my opinion a do-nothing technology would result in a slow decline of the productivity of most of the western ranges.

There are many technologies available that managers can apply to rangelands. However, almost all are site specific, and a technology should be applied on a prescription basis to each individual range site, rather than an overall technology applied to the western ranges. There is no overall panacea that will result in increased productivity of western rangelands. Currently some conservationists are advocating the removal of all domestic animals from the public rangelands of the West. In my opinion even this drastic action would not cause a rapid increase in condition or productivity of the range. In fact, in some cases it could cause a decline in conditions, especially when productivity is measured in terms of water yield, aesthetics, recreation, etc.

Some technologies have undesirable effects, especially if they are improperly applied. For instance, some herbicides, applied indiscriminately may cause human health hazards. The use of fire, although a natural range improvement technique, can also denude areas and cause increased erosion. Grazing management, particularly schemes such as rest-rotation grazing that concentrates large numbers of animals for short periods of time, are very effective tools for managing rangelands. Again, if applied to the wrong site, or in the wrong season, or to unadapted vegetation they may increase erosion and actually lead to a decrease in productivity, especially of arid rangelands. The concentrations of animals that are necessary for rest-rotation grazing may prove to be a specific danger to endangered plant species, when those species are no longer able to sustain themselves in remote corners of the range that were only moderately grazed year-long.

In summary, productivity of rangelands of the intermountain and mountain states can be increased with the proper application of technology but may be decreased if technology is improperly applied. There is no single activity or management scheme that will increase productivity on all sites. It cannot be stressed too strongly that technology for rangeland improvement is site specific and, unless the conditions of the site are completely understood, it may be impossible to predict whether the application of a particular technology will increase or decrease the productivity of the rangelands. Most of the ranges of the intermountain, mountain, and Pacific northwest region are either arid or mountain ranges on steep slopes that are particularly vulnerable to misapplication of technology.

There are a number of technologies that are currently used for the improvement of rangelands. These have been discussed in some detail by Vallentine (1971). Broadly speaking, they can be grouped into the following categories: adjusting animal numbers, controlling animal use, noxious plant control, noxious animal control, and reseeding and rehabilitation.

Every range site has a basic carrying capacity, and if this carrying capacity is exceeded the range will deteriorate. There are, however, some very basic problems in determining carrying capacity. The first is the extreme variability in productivity of most rangelands. The erratic and poorly-distributed rainfall causes plant production to vary more than 300% between years. This feast and famine condition is a common characteristic throughout the intermountain and Pacific northwest states. Therefore, any determination of carrying capacity must take into consideration a complete cycle of years rather than any single year.

The carrying capacity of a range is also related to the kinds of animals that use it. Most rangelands in the intermountain region produce forage plants that are suitable for two or more different species of animals. Therefore, if only a single species, such as cattle, is stocked, the carrying capacity is lower than if cattle, sheep, and goats were used. It is also possible to have a higher carrying capacity with a combination of domestic and wild animals that eat different kinds of plants. The carrying capacity for a combination of wildlife and several classes of domestic livestock is often higher than for a single class. It is also possible to use a class of domestic animals, such as sheep or cattle, to manipulate vegetation and increase the forage availability for wildlife, such as deer (Smith, 1949).

Another problem with determining carrying capacity of rangelands is that the measurement techniques available to biologists and statisticians are not sufficiently accurate to determine exactly what the carrying capacity is in any given year, much less in a cycle of years. The only sure way to determine carrying capacity is to make a scientific estimate by measuring vegetation in the field, then stocking the ranges and monitoring the trend of ecological succession or the change of the plant community through at least two drought cycles. Unfortunately, not many grazing districts in the intermountain region have had this type of treatment, even though they have been grazed for decades. In many of the environmental impact statements now being written the carrying capacity is based on a one-time measurement of forage rather than on a monitoring of stocking rates through a longer period of time.

Even when carrying capacity is accurately determined, the problem of determining proper animal use remains. It is essential that the range be grazed at the correct season of the year. Some plants are extremely vulnerable during a short period of their life cycle, and should be grazed at some time other than this weak period, or deferred during times of stress. What is good for the plants is not always practical or best for the rancher who grazes domestic livestock, and it may not be possible to control the wild animals when they graze at a particular time.

The ranges of the intermountain and Pacific northwest states are generally rough with poor distribution of water. Livestock, therefore, do not use the areas evenly. Techniques have been devised for distributing the animals over the land to increase productivity and numbers of animals grazed. Such techniques as herding the animals, placing salt away from water, developing new water holes, and fencing, are common to improve distribution.

Range managers have developed planned grazing systems that attempt to combine the regulation of numbers of animals, regulation of seasons of use, proper distribution of animals, and others discussed earlier. Many different terms have been used to describe grazing systems, and there are some inconsistencies in their use.

One of the more simple grazing systems is rotation grazing. This simply involves subdividing the range into units and grazing one range unit, then another, in regular succession. Another type of grazing system is called deferred grazing. This means delaying the onset of grazing in an area for a particular purpose, such as allowing old plants to gain vigor or new plants to become established. These two concepts have been combined into a system called deferred-rotation grazing. Under this plan a part of the range is deferred for a certain period, and then other parts are in rotation so that in the series all units will benefit from the deferment.

Rest-rotation grazing is similar to deferred-rotation grazing except that a unit is usually rested for at least an entire year. These basic concepts have been developed into a number of systems with particular jargon, such as switchback systems, high-intensity, short-duration systems, Merrill four-pasture systems, Hormay rest-rotation systems, etc.

These planned grazing systems have some distinct advantages. Almost all result in better distribution of livestock over the area. They also allow for plants to be deferred during vulnerable periods. Many of these systems have reported rather startling results as far as improvement. Others show little or no effect and, in some cases, have actually been thought to cause range deterioration. Hickey (N.D.) reviewed 115 papers dealing with planned grazing systems and concluded that no one system could be applied to all ranges. It is my opinion that planned grazing systems offer a special and unique way to improve rangelands. However, they are site specific and should be considered only after the soil, vegetation, and ecology of the site are completely known. These grazing systems have been discussed in more detail in Stoddart, Smith, and Box (1975) and Heady (1975). They cannot be considered as a panacea or cure-all as some of the public land management agencies have seemed to indicate in the past.

There are two classes of noxious plants whose control would increase productivity in the intermountain and mountain rangelands. The first are native plants that have increased in numbers due to some disturbance such as overgrazing, control of fire, or overcutting forests. Such plants as pinyon-juniper, sagebrush, and other woody plants have increased at the expense of herbaceous plants that provide forage for grazing wildlife and for domestic animals. The other major type of noxious plants are introduced exotics that have been released because of accidents and have established themselves on the rangelands. Plants such as halogeton fall into this category. In general, any plants that utilize the limited moisture and decrease production of more desirable plants are considered noxious or pest plants.

There are three major approaches to controlling noxious plants: chemical, mechanical, and fire control. Chemical control has advantages in that it is effective, various chemicals may be selected that are specific to individual plants or groups of plants, and it is relatively cheap when compared to other types of control. Major disadvantages are that some chemicals, improperly applied, may cause crop damage or health hazards. Current environmental concerns and strict EPA regulations have largely prohibited the use of chemicals in most of the rangelands of the West.

Mechanical control methods vary all the way from hand-clearing or chopping individual plants to the use of big machines that plow or drag the plants from the ground. These methods are advantageous in that the plants are removed immediately while the residue remains on the ground as organic matter or ash. There are distinct disadvantages in that the cost is generally high and a considerable amount of soil disturbance occurs with most mechanical methods.

Fire is a natural factor on all of the rangelands of the West. It is again becoming accepted as a major plant control device. It has advantages in that it is fairly inexpensive and effective against non-sprouting species. It has disadvantages in that it is often difficult for many brush areas to carry a fire, and the land is denuded for a short period of time after allowing erosion from flash storms.

There are various biological controls, such as the use of domestic animals or introduced insects and invertebrates. The only major biological control that appears effective at the present time is the use of domestic livestock to manipulate plants.

These plant controlled mechanisms, either alone or in combination, offer a technology that can increase the productivity of the western rangelands. Again, it must be stressed that these mechanisms are site-specific; and the exact number of acreages suitable for treatment and the response to them are difficult to predict from the amount of data available. Although the RPA (USDA, 1980) gives broad generalities as to the amount of each vegetation type that can be expected to improve with various plant-control treatments, the techniques and methods under which it is presented make it difficult to accurately assess the amount on each individual geographic area or the total beneficial response to be achieved.

Noxious animal control is another technology that is available to increase rangeland productivity. Most livestock people list predator control as a very high priority. The control of predators that attack livestock would undoubtedly increase the amount of livestock taken from the land and, in that case, increase overall productivity of domestic animals. However, large numbers of small herbivores such as rabbits, gophers, and prairie dogs consume plants that are eaten by domestic livestock, and no accurate estimate has been given of the amount of forage that would be consumed by increasing populations of these small herbivores, once predators were controlled. In my opinion, the control of predators would increase the economic yield to the livestock industry, though it is doubtful that it would serve as a major range improvement technology.

It is easy to see, however, that the control of the increasing numbers of large, exotic herbivores in the West does have an impact on the rangelands. Thousands of horses and burros occur throughout the western United States. They are feral domestic animals which compete directly with domestic livestock and in many cases may compete directly with wildlife as well.

Another broad subheading of the technology available to increase productivity of rangelands is that area of rehabilitation, seeding, and reseeding of rangelands. It has already been pointed out that the arid rangelands of the intermountain region are slow to heal themselves under natural conditions. Therefore, those areas that are extremely depleted may be in need of artificial help to return to productivity in any reasonable length of time. Seeding and reseeding of rangelands may include the clearing of woody species and seeding native grasses or exotics such as crested wheatgrass and Russian wildrye. Mixtures of grasses, herbs, and browse could be used by a number of different kinds of animals.

Much of the private rangeland has been reseeded to grasses primarily for domestic livestock. Since early spring grazing is usually at a premium, such exotics as crested wheatgrass have filled this niche well. There are some wildlife biologists who claim that this practice has reduced the total amount of forage available for deer herds. Others show that this early spring grazing may actually benefit deer herds. In the past few years considerable research has been done in ways to enhance, improve, and reseed browse vegetation that can be eaten by wild animals.

With the increasing amounts of lands used for mining operations, road cuts, military bases, etc., a new technology in rehabilitation of drastically disturbed lands has emerged. This technology can help restore these disturbed lands so that normal range multiple uses can be practiced.

Few disturbed rangelands have reached the point where deterioration is totally irreversible. Those that have may have suffered drastic disturbances such as strip mining, road cuts, reservoirs, etc., and may recover only if special rehabilitation technologies are applied.

The concept of drastic disturbance is one that has developed the last few years among rehabilitation specialists. In general an area can be considered to be drastically disturbed if the native vegetation and animal communities have been removed and most of the topsoil lost, altered, or buried (Box, 1978). These drastically disturbed sites will not heal themselves within the lifetime of a man through normal, secondary successional processes. The process of rebuilding the plant community must start from a new growth medium, usually a mixture of subsoil, rocks, and soils. Plants and animals have been completely removed and must reestablish themselves within the area disturbed. The natural process often must be helped by artificially introducing new plant communities or by altering the conditions under which the new plant communities develop. Even drastically disturbed rangelands, therefore, are not totally irreversible if enough inputs are utilized.

Rangelands of the mountain, intermountain, and Pacific northwest areas, however, will be extremely slow to recover. The length of time needed for recovery under natural conditions is roughly related to the aridity of the area. On high mountain sites with deep soil that receive 40 or 50 inches of rainfall it may be reasonable to expect ranges to recover from disturbance in a period of years. On areas that receive 15 to 20 inches of precipitation it may take decades to rebuild lost communities. In some of the areas where less than 10 inches of rain occurs it may take centuries for the area to reestablish itself and recover from heavy disturbance.

The question then is not whether the heavy use of rangelands is an irreversible process, but whether society is willing to wait for nature to reverse itself and heal a heavily used range that may take decades or centuries to regain its original productivity. Fortunately, the process can be speeded up. The rebuilding process is site-specific and in some cases inputs of labor, water, fertilizer, and other materials will allow the area to regain its productivity within a reasonable length of time. Most rangelands in the intermountain area will recover, given enough time and proper grazing management. It is also reasonable to expect that productivity on these same rangelands will increase much more rapidly if some of the technologies of range improvement discussed earlier are applied.

ADEQUACY OF RANGE MANAGERS

There are good range managers in the intermountaion region who are graduates of well-recognized range management schools and have adequate knowledge of the rangeland ecosystem. Unfortunately, their numbers are far too small. It has been pointed out repeatedly by the agencies themselves (BLM, 1974), by academics, and by the Society for Range Management that there are simply too few range managers to do the job required of them in the intermountain and mountain West.

Since there are not enough well-trained range people many of the decisions involving rangelands are made by non-range managers. They fall into two broad categories. One is line personnel who have little or no range management training. These people may have been trained in related fields, such as forestry, or they may have come up through administrative or engineering routes, but they find themsleves managing a grazing district for the BLM or supervising a forest for the Forest Service. The other large group of people are those who "qualify" as range managers under the inadequate Civil Service standards and fill jobs without the proper training. Until very recently anyone could qualify as a range management specialist with only 12 semester hours of range management. The western universities, the user industries, and the Society for Range Management all have testified that this minimal amount of training is inadequate for people to do the job. Still there is hardly a district in the West that does not include some people whose academic training does not qualify them for the range manager's position in which they are working. The new Civil Service standards going into effect in 1980 will help to alleviate this. However, if the older people who have already been hired under inadequate standards are not retrained, the problem of managing rangelands with inadequate knowledge will continue.

Even the best range managers must operate with data that are inadequate for the interpretation of the complex ecological processes on the rangelands. Unfortunately, the data are often inadequate even for estimating current conditions. As many as one-half to two-thirds of the districts in the intermountain and mountain states still do not have accurate carrying capacity estimates for the rangelands. Only a few BLM Districts and National Forests have current range condition and trend studies. Range condition data on private land is available only on those lands where the owners have signed up as Soil Conservation Service cooperators. Most state plans have little quantitative data and depend upon the surrounding federal lands for the data base for their management. Taken together, the data base, even to determine the current carrying capacity on rangelands, is inadequate. It is even more difficult to get data on ecological condition and trend of the rangeland.

Data on the seral processes of most range sites is almost totally lacking. There are few sites on which the potential can be accurately predicted. Productivity data of each seral stage related to specific outputs or products in that seral stage, is almost unknown. Much more information is needed to determine the major forage plants response to to defoliation or grazing. The major critical periods of the life cycles of the plants are not well known. Managers need to know which plants can survive various kinds of stresses. These kinds of data are not just academic. They are essential for the designing of adequate planned grazing systems that will cause one group of plants to be favored over the other.

Data on economics and social conditions in the western range area are sparse and scattered in many sources. Taken in total, the kind of information available for the range manager to interpret the complex ecological processes of the range he managers is almost totally inadequate.

Add to this a major problem of communicating what is known to the managers on the ground and one wonders how the ranges have been managed as well as they have. No profession can survive, no professional can grow in his field, without some form of continuing education. Unfortunately, range management professionals have not had the kind of in-service training that is necessary to keep them current.

One major criteria of a professional's ability to keep current is his activity in his professional society. A professional who serves as an officer in his society, one can assume, is attempting to mold and change the concept of his profession. Box, Dwyer, and Wagner (1977) compared the activities of management agency personnel in the Society for Range Management between the years of 1957 and 1976. At that time there were roughly 5,000 members of the Society for Range Management. In the year 1976 BLM had 353 people in the Society; U.S. Forest Service, 776; and the Soil Conservation Service, 572. The three agencies combined contributed only roughly one-third of the membership of the Society. It was not known how many total federal employees who claimed to be range managers were employed by the government in 1976. The participation of the three agencies as officials in the Society was likewise bleak.

There may be a number of reasons why range managers in the land management agencies do not participate in their own professional society. There have been extreme restrictions on travel in recent years. However, managers who are active in their own profession, involved in planning the meeting, and interacting with their professional societies are most likely to stay current.

Workshops and seminars on range management are offered at almost every land grant university within the intermountain and mountain states, but because of limited enrollments only a small percentage of range managers can be included in these kinds of educational activities. Few people return to the universities for formal coursework or degree programs. A major exception is the cooperative education program for young scientists and managers in which a student works part of the year and goes to school part of the year to gain either a bachelor's degree or, in some cases, an advanced degree. Unfortunately, there are far too few of these kinds of activities. In general, the communication between scientists, either in the university or in the Forest Service research branch, and the line managers is not adequate. Far too often the scientific research is producing information that would be applicable in the field, but the results are being published in technical and scientific journals that the range managers may or may not read. On the other hand, the range managers working in the field are seldom able to express their frustration and needs as researchable questions that can be addressed by the scientific community. The major contact between most professionals in the field and the scientific community appears to be through personal contact with scientists at their alma mater or a nearby educational institution. These conditions argue the need for more informal contacts such as workshops, seminars, professional society field trips, or working sessions.

The Renewable Natural Resources Extention Act was passed in 1976, but is yet to be funded. There appears to be a major need for a research-oriented person to work as an intermediary between the land manager in the field and the research scientist in the Forest Service and on the university campus. On one hand, this extension person would take the information developed by research scientists and make it understandable and usable to land managers. On the other hand, he would look at the land managers' daily needs as problems to be assessed, restated, and developed into researchable projects that would help solve new problems as they arise. One of the major needs is to determine which of the information already available is applicable to situations that face the land manager today. It is equally important to identify problems that must be solved and then place those problems before the research institutions. It is really the land managers who should establish priorities for research.

Range research has never been adequately funded. Studies by Box, Dywer, and Wagner (1977) and others (Klemmedson et al. 1978) have shown that other types of land use such as agricultural commodities and intensive forestry receive many times more research support than do rangelands. Therefore, although some important general research has been done, much has been left undone. Much of the research has been geared to understanding a particular site and has little predictive value. The greatest overall needs in range research are to understand basic processes and to develop research studies that will help understand principles that could be applied to other sites and regions.

Since almost every technology dealing with the management of rangelands uses the successional process in some way, research dealing with understanding successional phases and processes must have a high priority. A good example of this type of research would be a study designed to determine why and under what conditions bunchgrass rangelands in the intermountain area or the Pacific northwest turn to sagebrush type. More important, research is needed to understand the process of change and to itemize and predict the goods, services, and outputs available from each successional stage. This kind of research would allow the range manager to write prescriptions that would move plant succession forward or backward and would get the kind of mix of goods and services that society desires.

It may not be possible to totally understand succession without first understanding the autecology of the plants on the rangeland. Therefore, equal priority should be placed on the study of the ecology of individual plants. Their ecophysiology will dictate the kinds of manipulations that are possible and help predict results from any given manipulation. A better understanding of the stress physiology of plants should be one of the objectives of these autecological studies. Most range plants are stressed at some period in their life cycle. This stress may come from drought, extreme winter cold, extreme summer heat, defoliation, or trampling. All of these results have been described in an empirical manner, but even after almost a hundred years of research the basic physiology of many of the plants simply is not known.

The ecology of fire and how it fits into the manipulation of rangelands is an important research field that should be high in the priorities. With increasing costs of mechanical control, and with the public concern for health hazards in chemical control, natural methods such as fire are destined to be major tools of the range managers.

The design of grazing systems based on the autecology and synecology of plants discussed earlier is an important next step in research on rangelands. Coupled with this is the need for more intensive research on biological control of plants. If domestic or wild animals can be used to force successional patterns from an undesired position to a desired position, range improvement can be brought about while red meat is being produced at the same time. There is now wide use of the various planned grazing systems, without adequate basic information about what should happen on the rangelands. I would suggest that we have enough graze-it-and-see-what-happens research. We should first develop the basic information on plants and soils, and then use the grazing system to design and test the hypotheses arising from the basic research.

Additional studies on the population dynamics of wild and feral domestic animals are sorely needed. Domestic animals can be controlled; however, herds of small and large herbivores build up periodically on the rangelands. More information is needed on their population dynamics. This is especially true with feral animals such as the wild horse or burro.

More creatively designed financial systems that will encourage stability in ranching operations under the feast-and-famine conditions that exist in the intermountain region should be a high-priority item. These kinds of research projects should study not only the economics of the ranching industry, but their relationship to surrounding communities. We should know what kind of support institutions are needed to allow livestock to use the highly variable resource, and at the same time keep nonlivestock resource values available to the public.

More work is needed to clarify the resource allocation processes for integrated planning and management. Both the National Forest Service Management Act and the Federal Land Management and Policy Act require that the public lands be managed on an integrated basis, and that data be developed by interdisciplinary teams. While these concepts appear good on the surface, in many cases the tools are not available with which to collect the basic idea needed and integrate them into a single land use plan in which resources are properly allowed to get the various outputs that society needs.

With the great increase in drastically disturbed lands throughout the West, additional research is needed on the processes involved in rehabilitating severely damaged landscapes. Much work has been done in the last half century on reseeding deteriorated rangelands. However, on these areas soil was still available and at least some kind of plant community usually existed. On more drastically disturbed soils we need research on the stress ecology of plants living under extreme saline or toxic conditions. Research on the soil-forming process itself is needed. If the estimate is correct that intermountain and mountain state ranges are producing only half their potential, there should be a number of development or improvement opportunities. In my opinion, the highest development priority is to obtain a data base sufficiently accurate to tell what is presently available, which successional stage exists on the particular area involved, and some estimate as to what its potential productivity may be. With this information treatment can be applied to those areas that have the best chance of responding quickly.

Generally speaking, the spring-fall ranges of the mountain and intermountain area are in short supply. It would seem logical, then, that the first priority would be to develop spring-fall ranges where livestock spend much of the early spring and fall, and where most of the big game animals spend the winter. Much of this land is in private ownership and the development will have to be done through the use of private capital and incentive programs. Some of this land is near cities and has a high potential for residential or industrial development.

Generally speaking, the summer ranges in the mountain and intermountain states are in better condition than the spring-fall or winter ranges. However, I would consider them as a lesser priority for improvement, because their potential is greater and production increases as rainfall increases.

Finally, development capital should be spent in improving the winter range, even though under these arid conditions it will take longer to bring them back to their potential. The return on the investment will be less than in the summer or spring-fall ranges, but they are generally in poorer condition than the summer ranges.

One of the best ways to ensure proper management of the rangelands in the intermountain area is to apply what is already known. This implies an active education and extension program geared toward several publics.

Ranchers and other land users should be a prime target for a major educational program. It is my opinion that people who actually use the land have more interest in and a higher stake in the land than nonusers. This would apply to ranchers, hunters, campers, and all sorts of people who have specific contact with the land. When these people are shown what is good for the land, they are more likely to apply technology and use than those who have no vested interest in the area.

A major need is to educate users on the principles of multiple-use and integrated planning. Good shortcourses on these subjects could lower tension between management agencies and users, and lead to more rapid development of rangelands.

Another major educational need is to retrain the professionals who are now managing the land, to give them the modern tools of the trade. These retraining activities can best be done by land grant universities through shortcourse and extension programs.

A more general need is to instill in the general public an appreciation for the special needs of arid ecosystems. Many people from the urban areas merely drive through desert rangelands and then conclude that they are worthless. Some think the land has been heavily over-grazed and is not producing. In reality, what they are seeing is simply a result of the arid conditions under which the plants have evolved and grow. The need to provide for education and extension of what is already known is great. Most land grant universities in the West are capable of filling that need, but funding has not been adequate to allow aggressive programs in adult education.

GOVERNMENT POLICIES AND INFLUENCE ON RANGELANDS

There are a number of government policies that affect the use of technology on the intermountain rangelands. Perhaps the most pervasive and overwhelming policy is an unstated attitude that the arid and semi-arid rangelands have little value to society. Policies imply that they can best be used for disposal of any waste products that the rest of society does not want. The development of huge bombing ranges, missile bases, etc. may be viewed as the most efficient use of the lands. This attitude is easy to understand since the desert rangelands are by nature low in productivity. There is also a small human population base and few people can voice outrage at policies that tie up the land for a single-use purpose.

There are already large areas, often the size of many small eastern states, that have been made into national sacrifice areas by designating them as bombing ranges or nuclear test sites. If this attitude continues to prevail and such weapen systems as the MX missile should be deployed in the desert, or if, indeed, there is a national policy to use these low-producing lands for disposal of nerve gas or nuclear materials, even larger amounts of the West will undoubtedly become national sacrifice areas.

It may well be that the desert rangelands of the intermountain area are the best location for such single-use, land-destroying purposes as military test sites. However, the decision to take land out of productivity, regardless of its low potential, should be made only after adequate data have been collected and the tradeoff of loss of that land evaluated against the benefits to society. Unfortunately, this has not been the case in the past, and the government policies in general simply assume that the intermountain rangelands are an area in which to put everything that the rest of society does not want.

The policies on integrated planning and resource allocation for multiple use have been stated well in such recent acts as the RPA, NFMA, etc. In principle the policy of integrated planning for multiple use is good; however, the implementation of this policy has led resource managers to become more concerned with the procedure for meeting the laws than with management of the land itself. A good example of this is to be found in the Natural Resource Defense Council suit against the Bureau of Land Management, that forced the Bureau to write grazing environmental impact statements. The problem if there was one, was that the land was not managed properly. The NRDC took the Bureau of Land Management to court and won their case. The judge directed the Bureau of Land Management to write 212 environmental impact statements. Much of the effort of the Bureau has been for the last few years, and will be for the next 10 to 12 years, in writing good environmental impact statements. There is no evidence that the land management problems that originally created the controversy have been corrected. In fact, it may be that the requirement to follow strict procedures on environmental impact statements has taken some of the best land managers away from the land and put them into the office producing stacks of paper.

There is a growing fear among the academic community that the planning process now being implemented (Section 6, NFMA) by the Forest Service and the planning processes by the Bureau of Land Management will further cause these agencies to be concerned about the procedure and to think like lawyers rather than resource managers.

The pest control policies on the intermountain rangelands are a mish-mash of different directives, apparently stemming from very different philosophical bases. Some are geared to protect an exotic animal, wild horses, or an endangered species of plants that is close to extinction because of the build-up of protected wild horses. There are different agencies charged with control of grasshoppers than are charged with control of coyotes. Administrative edicts may take away major to[illegible], such as the use of herbicides or 1080 poisoning, for such different reasons as human health and safety and public resistance to poisons in general. It is perhaps too much to hope that pest-control policies will be viewed in a systems context and controlled by the agency or individual managing the land, rather than various competing bureaucracies.

Mining and other extractive industries will continue to grow in the West. Policies dealing with the exploration, extraction, and rehabilitation processes will be important in determining whether the land can be used for rangeland uses in the future.

There is perhaps no more controversial set of policies affecting the rangelands of the intermountain region than those surrounding the designation of wilderness or special recreational areas. Those agencies managing the rangelands find themselves between two highly vocal and philosophically different groups of people, one wanting all land open to economic uses and the other wanting a maximum amount of land set aside for wilderness and recreation use with other uses minimized. These issues have drained far more of the emotional capital from users and agencies alike than they actually deserve. The quicker the agencies get on with finalizing the surveys required by Congress and designate areas and release those not designated, the better. The designation of large areas for future study will only continue to aggravate a very sensitive issue.

The policies dealing with the grazing industry have come under attack in recent years. Much controversy exists over grazing fees, reductions of permits, etc. However, if the land is to continue to be grazed sensibly under a system that will allow the ranges to improve, then a major policy shift is needed. A policy should be developed that will insure the stability of the ranch operators, enabling them to cope with the highly variable conditions imposed by nature itself.

Policies on rangeland improvement also need to be clarified. The National Rangeland Improvement Act provided for restoring most western rangelands, however, it has not been adequately funded. An integration of the concept of rangeland improvement into the planning process discussed earlier can be a major step forward.

Government policies involving adult education need to be clarified. It appears that the intent of Congress when it passed the Renewable Resources Extension Act was to build and enhance a major adult education program. However, this Act has not yet been funded even at a minimal level. If, indeed, the Congress believes that the education of the general public and range users in the West is important, then the Act should be funded and Congressional reports should specifically state that the arid rangelands of the mountain and intermountain West are as important as the humid forests of the Southeast. Even before the Act has been funded much struggle between foresters and range managers has surfaced. Attempts are being made by forestry schools in the south to minimize the amount of work done on rangelands. The policy of Congress on what was actually intended when the Act was passed needs to be clarified.

Qualifications of personnel managing the western rangelands needs to be changed. In the past the Civil Service standards have been so low that almost anyone could qualify as a range manager. Recent changes by the Civil Service Commission now allow only well-trained people to enter the government service as range managers. Policies are still flexible enough to allow someone to enter the service as a nonrange manager and transfer over to managing rangelands. These kinds of loopholes need to be plugged.

In recent years government agencies have adopted policies that only native plants should be used for reseeding or rehabilitation purposes on rangelands. In theory this may seem logical; however, much of the rangeland is severely deteriorated. On drastically disturbed sites the environment may be changed to the extent that it would be better ecological procedure to seed a weedy plant and get an immediate cover than to try for a native plant in one step.

SUMMARY

In general, the rangelands of the intermountain and mountain West are in the best condition they have been in this century (Box, 1978, 1979). Most of them deteriorated within one or two decades after the introduction of domestic livestock and were in poor condition by the turn of the century. There is good evidence that those rangelands of the higher elevations have improved in the last few decades. Some improvement in general has been noted in the desert rangelands. There is no doubt, however, that there are certain districts and restricted areas where the rangelands are in poor condition and where they continue to deteriorate. These areas need immediately attention to reverse the downward trend. It may not be logical for society to wait the decades or centuries that are necessary for nature to repair them on its own.

There are no technologies that can be applied to all sites. The treatments needed are extremely site-specific and should be presented under the direction of a well-trained range manager.

Although the rangelands are in the best condition that they have been in a hundred years, there is no doubt but what they can be much better. Many professionals now feel that the productivity of the rangelands of the intermountain region could easily be doubled. Technology is available to restore those lands to their original productive condition; however, it will take money, time, and well-trained personnel. The decision is not whether these rangelands can be improved but whether society wants to make the investment.

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Background Paper No. 3

LIVESTOCK GRAZING ON THE FORESTED LANDS OF THE EASTERN UNITED STATES

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SUMMARY

Favorable climate and soils have endowed the Eastern U.S. with the capacity to produce an abundance of livestock forage. This forage potential has been developed through a variety of production systems designed to meet social, ecological and economic needs. Forage production through improved pasture management is the region's major source of livestock forage. Pasture output is so great that other sources of forage have been eclipsed in land use inventories, educational activities and applied research. Forage potential on forested lands is particularly lacking in documentation. The purpose of this report is to increase understanding of the Eastern forest's potential to produce livestock forage, and build a foundation for future work to develop this potential.

The 310 million acres of forested land in the 30 Eastern States are that region's greatest potential source of naturally occurring vegetation suitable for livestock grazing. It is estimated that these forested land could support nearly 20 million cow-calf units each year if the forest was intensively managed for multiple products. However, the technologies for implementing such multiple-use management have not been developed and tested for most Eastern forest communities. Only limited progress is being made in developing these technologies because of the commonly held attitude that native forages on Eastern forests can not be produced and grazed in an economically and environmentally sound manner. Two hundred years of history reflecting changing social and economic factors have created these negative attitudes toward livestock grazing on the Eastern forests. The overall historical pattern for the region's forests has been similar although the specifics for the Northern hardwood forests differ from those of the Southern pine forests. Traditionally, forested lands have been considered open range and livestock grazing has been conducted with few management inputs. Overgrazing was frequent, thus soil erosion and damage to trees were

common. Opposition to forest grazing began with the advent of scientific land management.

The need to conserve the land base while increasing production triggered the development of scientific land management in the mid-1900s. Exploitive timber harvesting left 350 million acres of clear-cut forestland in the Southern states, plus millions more in the North. Reestablishment of the forest required livestock grazing to be restricted and led to the continuing conflict between the livestock producer and the forester.

In recent years, there has been a decline in the number of acres of Eastern forestland being grazed by livestock; between 1967 and 1977, acreage of grazed Eastern forestland dropped from 80 million acres to 36 million. However, this decline does not appear to reflect a change in many farmers' willingness to graze livestock in the forest. Over the past 20 years about half of these farmers grazed livestock on their forested land; however, such grazing remains extensive with few management inputs and continuing adverse environmental impacts. The major change in the last 30 years has been in forest ownership. The farming sector now owns only 30% of the forest acres.

The loss of this 50 million acres of forestland from the farming sector appears to be due to economic factors. Although forest grazing continues, analysis indicates that it is unprofitable as now practiced. The farming sector also profits very little from the sale of wood products — earnings per acre of farm woodland averaged less than $5 in 1974.

Millions of acres of Eastern forests are not being managed for the production of goods or services at this time. If these lands are to once again be a national resource, new management technologies must be developed which will meet the various economic and social needs of all user groups.

I. INTRODUCTION

Scope and Purpose of This Report

This report focuses on the forested lands of the Eastern United States and assesses the role of livestock grazing on these lands. Three questions are addressed:

1. Which of the Eastern forest-types have the potential to be native grazing lands? The term, native grazing lands, refers to those forest and grassland ecosystems with naturally occurring vegetation suitable for livestock grazing that can be used in a manner that is both economically and environmentally sound. There is some controversy regarding the areas of the Eastern U.S. that meets this definition. Forested lands are the center of this controversy since most of the region's native grassland is now cropland in the nation's Corn Belt.

2. How is the forested land of the Eastern U.S. being utilized for livestock grazing, and how does grazing interact with other uses of the forest? An examination of the history of use of these lands provides many of the answers to these questions.

3. What technologies are used to manage Eastern forests for livestock grazing and how do these technologies impact on the resource? Attempts to answer this question will concentrate on the grazing animal. The grazing animal is the primary tool for managing grazing lands, along with being the harvester of native vegetation. Some information is available on livestock impacts; however, documentation on other technologies associated with livestock grazing is very limited. Therefore, answers to these questions will be brief.

The Eastern U.S. is defined as that geographical area east of the 97th meridian. This line basically excludes the Great Plains States but includes the forested lands in Oklahoma and Texas. The northern and southern halfs of this area are treated separately because of major ecological and cultural differences. The Northern and Southern regions will be further divided into four sections each to better reflect local variations. Appendix I shows how these 33 states are divided into these regions and sections.

Characteristics of the Region

The land base of the Eastern U.S. has a huge potential to produce vegetation. The East is blessed with rainfall, long growing seasons and good soils. Despite years of settlement and urbanization, much of the land is still rural and can be used for agriculture including the production of forage for livestock.

The primary source of forage comes from intensive crop and pasture management on land cleared of natural ecosystems. Native grazing lands are of secondary importance in terms of total forage output although they cover a large area. Croplands as well as pasture land produce forage suitable for livestock grazing.

The Eastern states have 250 million acres of cropland that can support livestock grazing (Table 1.1). Croplands supply forage in two ways: 1) crop rotations often include a forage cover crop for soil conservation and these forages can be grazed and/or harvested for livestock use, and 2) cropland can be grazed following harvest of the crop in the fall. Residues and stubble left from the harvest of grains are frequently grazed. Both of these practices provide only temporary grazing and livestock must be removed prior to planting the next crop.

Although croplands are important forage sources, pasture land is the more important in terms of overall production. Pasture is defined as land producing forage through intensive cultivation and management. These lands are usually planted with introduced or domesticated forage species of grass and/or legumes and receive periodic renovation through such treatments as tillage, fertilization, mowing, weed control, and irrigation (27). Under such intensive management, yields are estimated to average 5 tons of forage dry matter per acre per year which would produce about 1500 pounds of liveweight beef gain (28). However, most of the 110 million acres of pasture in the Eastern U.S. is not managed this intensively.

Table 1.1. Use of Non-Federal Land in 1977, by Region and Section; Acres of Total Land Area Used for Urban and Other Uses are not shown. Source: Derived from "Basic Statistics: 1977 National Resources Inventory (NRI)," Soil Conservation Service, USDA, Revised February 1980.

	000's of Acres				
Region and Section	Total Non-Federal Area	Cropland	Pasture	Forest	Range
Northern Region	423,664	157,398	45,649	150,751	114
New England	39,184	2,290	1,099	28,897	0
Middle Atlantic	84,846	15,617	6,773	44,072	0
Lake States	113,906	44,141	6,857	42,388	114
Central States	185,728	95,350	30,920	35,394	0
Southern Region	488,734	95,253	64,954	161,202	113,588
South Atlantic	70,643	12,737	6,546	40,816	0
East Gulf	67,109	9,676	8,717	33,706	3,017
Central Gulf	85,425	16,729	13,637	45,842	30
West Gulf*	265,557	56,111	36,054	40,838	110,541

* West Gulf includes all of Texas and Oklahoma although only the eastern forested portion of each state is directly related to this study.

Native grazing lands are important even though pasture and cropland will continue to dominate total production. As indicated in Table 1.1, there is little more than 3 million acres of rangeland (native grass and shrub lands with few trees) in the Eastern U.S. when Oklahoma and Texas are excluded. This rangeland is potentially very productive, but because of its small area (largely concentrated in Florida) it is mainly of local interest. The Eastern forested lands are the most important native grazing lands with a total of 300 million acres.

The Eastern forests are ecologically heterogenous. Such factors as terrain, soil development, vegetation structure and composition, and climate greatly affect the forest's potential to support livestock grazing. Although many forest ecosystems can support livestock, others would require extensive modification.

An important question regarding native grazing lands in the Eastern U.S. is: Which of the forest ecosystems have the potential for livestock grazing? The most basic technology used for grazing lands is the grazing animal and its management. The decision to put grazing animals on a forested area results in major impacts on the land and the animal. These impacts are generally adverse when grazing animals are put on unsuitable forestlands. Therefore, the first step in evaluating the native grazing lands of the Eastern U.S. is to determine which forest types should be grazed.

Defining and Classifying Eastern U.S. Grazing Lands

Grazing lands vary greatly, so there are no simple criteria for defining and classifying them. For example, land is classed as "range" if it is a native grassland, but if hay is harvested on the range, the land may be classed as "cropland." Even the most basic divisions can lead to confusion and fail to identify the full status and potential of the land base.

Problems of land definition and classification extend beyond mere academic interest. Various government agencies have difficulties inventorying the land base to determine land use capabilities and assigning administrative responsibilities. The most serious problems seem to arise when a term can be used to describe both a land use and a land type.

An important classification problem in Eastern grazing land classification stems from the dual definition of "range." For a number of years, "range" was considered a land use (i.e., grazing livestock on native forages produced on grasslands, shrublands and forests). However, "range" is now being considered a land type with "range" being defined as lands on which the native vegetation at ecological climax is predominately grasses, grass-like plants, forbs or shrubs suitable for grazing or browsing use (27).

Major national land inventories often intermix land use and land type within the same inventory because distinctions between natural and man-made land types are blurred. For example, almost all of the Eastern U.S. was once forested; yet inventories such as that in Table 1.1 indicate large areas of cropland and pasture land. Cropping and pasture can be considered uses of forest land since all of these lands would revert to forest in the absence of man. But what of the 300 million acres of forested land? How much of it is being used for livestock grazing and should be classed as "range"? How much is being managed for wood products, and should this be classed as improved forests?

Many land inventories class natural lands by type, i.e., forest, range, desert, etc., but lands modified by man are classed by use, i.e., urban, crop, pasture, etc. The problem with this is that the major use of the natural lands must be assumed. Even if such use is indicated, information is usually not provided on secondary uses.

Fortunately, some efforts have been made in some land inventories to take forage producing potential into account. Various modifications of terms have been made in an attempt to establish criteria for such inventories. Among the more common terms are the following:

> "Forest Range" is one of the older terms for describing and using the forage resource under the forest canopy. This term is now falling into disfavor because it confuses land use and land types.
>
> "Woodland Grazing" is a term for land use, and "Grazable Woodlands" is a term for land type where livestock can be grazed under a forest canopy, on native forages. The term woodland has taken on a more precise meaning in some circles by referring to open or park-like forest where there are many breaks in the forest canopy.
>
> "Transitory Range" is beginning to be used to refer to the open native grasslands that develop in a timber clearcut, and exist until the forest canopy is reestablished.
>
> "Native Pasture" can be described as permanent "transitory range"; that is, forest land that has been cleared, covered with native forages, and tree reestablishment is prevented.

Unfortunately, not even these terms are standardized; they find use only among specialized groups. As a result the few government agencies that do conduct inventories of forest grazing often use different criteria for classifying forested areas. This lack of consistency makes it difficult to evaluate the extent of grazing in forested areas. Specific examples of this problem are presented later in this paper.

The importance of these problems of defining, classifying, and inventoring forage production and utilization on Eastern forested lands can be understood best when seeking to examine the productive potential and use of these lands for livestock grazing.

II. PRODUCTIVITY AND USE OF EASTERN FORESTED GRAZING LANDS

Potential Productivity of Eastern Forests for Livestock Forages .

Only recently has an effort been made to estimate the forage producing potential of forested lands in the Eastern United States. This work was done by the U.S. Forest Service in complying with the Forest and Rangeland Renewable Resources Planning Act of 1974, as amended by the National Forest Management Act of 1976. Details of the Forest Service's findings are presented elsewhere (30) (31) (32) so only a brief overview will be presented here.

A major component of the Forest Service's estimates was a linear programming model (RAMAS) and its associated data base. The three most relevant elements of this modeling activity for the purposes of this paper are the definitions of land types, estimates of area occupied by each land type, and potential forage production of each land type under various management levels.

The land unit for the analysis was an ecological unit defined by Kuchler (33) and called a Potential Natural Community (PNC). Kuchler recognized 106 PNC's in the continental U.S. (the Forest Service added one more, "mountain meadows"). PNC's are based on the vegetation that would exist if European man had not settled the country. Each PNC was futher divided into 4 productivity classes to take into account variations in soil and topography that would substantially affect productivity and management.

The area occupied by each PNC was then estimated. Only those areas of the country still in forest or rangeland were counted as having potential for production of native forage. This was essential since large portions of some PNC's have been converted into pasture, cropland and urban uses and therefore, are not immediately available for range and forest use.

The most difficult step of the modeling process was deriving forage production values under alternative levels of management. A considerable body of published information was available to help estimate production values, particularly in the West and the Southern Coastal Plain. However, such published information from research and long term management studies is lacking for much of the Eastern U.S. Thus, estimates had to be made by Forest Service and Soil Conservation Service personnel who have developed and managed grazing programs in the various Eastern PNC's.

An analysis of the Forest Service's RPA data for forage production in Eastern forested PNC's is summarized in Tables 2.1 and 2.2. Table 2.1 describes Forest Service Region 9 which is the northern region of the Eastern U.S., while Table 2.2 describes Region 8, the southern region.

These tables indicate potential production values that are a weighted average of the 4 productivity class values contained in the data base. Production values at two levels of management are given.

"Extensive management" is defined as controlling livestock numbers within current carrying capacity of the forest, but with little effort to achieve uniform distribution of livestock or to increase carrying capacity through alterations of the forest canopy. Management investments are made only to protect the land base from damage (34).

"Intensive Management" is defined as maximizing the production and utilization of forage, but within a multiple use framework. That is, all available cost-efficient technologies and practices are used to improve production, quality and utilization of native forages, while maintaining the forest for wood products, wildlife and recreation (34).

Table 2.1. A Summary of Estimates of the Potential of Major Forest Communities Found in U.S. Forest Service Region 9, to Produce Livestock Forage Under Two Levels of Management. See Text for a Discussion of How the Estimates Were Made.

Potential Natural Community (No. & Name)	Total Grazable Acres (1000's)	Average Potential Production (AUM/Acres)		Average Potential Production (Total AU)		States Within Regions in Which Community is Primarily Located
		Extensive Management	Intensive Management	Extensive Management	Intensive Management	
84 - Great Lake Spruce-Fir	5,503	0.01	0.19	7,673	91,581	MN, WI
86 - Great Lake Pine	5,660	0.02	0.23	13,217	112,426	MI, MN, WI
87 - Northeastern Spruce-Fir	11,934	0.02	0.64	31,838	646,478	ME, NH, NY, VT
89 - Northern Floodplain	2,518	0.14	0.81	32,029	158,547	MN
90 - Maple-Basswood	1,690	0.0	0.87	0.0	122,693	IL, IA, MN, WI
91 - Oak-Hickory	14,310	0.14	0.63	146,536	890,662	IA, IL, IN, MI, MO, OH*
92 - Elm-Ash	18,556	0.0	1.17	0.0	1,650,284	IN, NY, OH, PA
93 - Beech-Maple	1,448	0.01	1.04	1,206	125,452	MI, OH
94 - Mixed Mesophytic	5,039	0.0	0.43	0.0	132,520	OH, WV*
95 - Appalachian Oak	15,309	0.0	0.25	0.0	424,419	CT, MA, MD, NJ, NY, OH, PA, RI, WV
97 - Northern Hardwoods	38,665	0.01	0.80	34,921	2,596,887	MA, ME, MI, NH, NY, PA, VT, WI, WV
98 - Northern Hardwoods-Fir	7,891	0.0	0.77	0.0	511,218	MI, WI
99 - Northern Hardwood-Spruce	10,421	0.05	0.38	43,370	334,452	ME, NH, NY, VT
100 - Northeastern Oak-Pine	1,471	0.02	0.80	31,209	88,817	MA, NJ, NY
101 - Oak-Hickory-Pine	3,587	0.05	0.85	8,528	305,214	DE, MD, MO, WV*

* This community also found in U.S. Forest Service Region No. 8.

Table 2.2. A Summary of Estimates of the Potential of Major Forest Communities Found in U.S. Forest Service Region 8, to Produce Livestock Forage Under Two Levels of Management. See Text for a Discussion of How the Estimates Were Made.

Potential Natural Community (No. & Name)	Total Grazable Acres (1000's)	Average Potential Production (AUM/Acres)		Average Potential Production (Total AU)		States Within Regions in Which Community is Primarily Located
		Extensive Management	Intensive Management	Extensive Management	Intensive Management	
91 - Oak-Hickory	32,113	.11	.69	294,369	1,846,497	AL, AR, KY, MS, OK, TN, TX*
94 - Mixed Mesophytic	5,203	0.0	.39	0.0	169,097	AL, KY, TN*
95 - Appalachian Oak	20,788	0.0	.24	0.0	415,760	GA, NC, SC, TN, VA*
101 - Oak-Hickory-Pine	71,069	0.01	1.11	59,224	6,573,882	AL, AR, GA, LA, MS, NC, OK, SC, TN, TX, VA*
102 - Southern Mixed	24,801**	0.20	1.04	413,350	1,972,360	AL, FL, GA, LA, MS, TX
103 - Southern Floodplain	25,607	0.01	0.39	21,339	832,227	AR, LA, MS, TN*

* This community also found in U.S. Forest Service Region No. 9.

** About 2 million acres of total are not suitable for intensive management.

The two Tables suggest that the forage production potential of the Eastern forests is substantial. Under intensive management, these forests could produce nearly 20 million animal units (AU's) of forage. (An AU is the forage required to support a cow and a calf for one year.) Under extensive management, with few technological inputs, potential production drops to about 1 million animal units. Also a number of forested PNC's produce so little forage under extensive management that they are not considered grazing lands. Examples include Elm-ash, Maple-Basswood and Northern Hardwood-Fir forests in the North and the Appalachian Oak and Mixed Mesophytic forests in the South. Consequently some 116 million acres of Eastern forest are not suitable for grazing unless managed intensively.

The USDA's 1979 Agricultural Statistics indicate that the U.S. beef cow (cows that have calved) herd numbered 37 million. Theoretically, the Eastern forest, under intensive management, could have supported over half of the nation's beef cow herd in 1979! (It should be remembered that the Eastern forest covers 310 million acres of highly productive land.)

To what extent is the theoretical forage potential of the Eastern forest actually being used? More specifically, how many acres are being grazed and under what levels of management?

Current Utilization of Eastern Forests by Livestock

Considerably more information is available on the utilization of Eastern forests by livestock than is available on the levels of forage production; however, the value of the information available is diminished by the problems of definition and classification discussed earlier.

Table 2.3 shows some of the variations in information when agencies use different assumptions and methods in collecting and analyzing data. Estimates vary greatly as to the number of acres of forest being grazed

Table 2.3. Estimates of Forested Land Area and Area of Grazed Forested Land by Three Federal Agencies Under Alternative Assumptions:

1. Forest Service - Source: "An Assessment of the Forest and Range Land Situation in the United States," Tables 2, 3 and 5.3. Prepared by U.S. Forest Service, USDA, January 1980. Estimates for total forested area and all ownerships;

2. SCS - Source: "Basic Statistics: 1977 National Resources Inventory (NRI), Revised February 1980," Table 5. Prepared by Soil Conservation Service, USDA. Estimates for non-federal lands only and for forested land with a commercial timber potential;

3. Commerce - Source: "1974 Census of Agriculture," Vol. 1, Chapter 4, Table 1. Prepared by Bureau of Census, Dept. of Commerce, April 1977. Estimates for farm woodlands on farms with yearly sales valued at greater than $2,000; about 80% of farm woodlands are on such farms in the East.

	Forestland As Defined By Agency (000's Acres)	Forestland Grazed By Livestock (000's Acres)	% of Forestland Grazed By Livestock
Northern Region			
Forest Service	174,532	32,462	9
SCS	150,751	13,130	9
Commerce	24,854	10,623	43
New England			
Forest Service	32,462	551	2
SCS	28,897	231	1
Commerce	1,648	390	24
Middle Atlantic			
Forest Service	50,686	3,178	6
SCS	44,072	1,870	4
Commerce	4,356	1,212	28
Lake States			
Forest Service	50,886	2,306	5
SCS	42,388	3,264	8
Commerce	6,516	2,922	45
Central			
Forest Service	40,498	10,236	25
SCS	35,394	7,765	22
Commerce	12,334	6,099	49

(Continued on next page)

Table 2.3. Estimates of Forested Land Area and Area of Grazed Forested Land by Three Federal Agencies Under Alternative Assumptions: Continued

	Forestland As Defined By Agency (000's Acres)	Forestland Grazed By Livestock (000's Acres)	% of Forestland Grazed By Livestock
Southern Region			
Forest Service	206,874	70,647	34
SCS	161,202	22,967	14
Commerce	32,767	15,375	47
South Atlantic			
Forest Service	48,709	6,791	14
SCS	40,816	2,318	6
Commerce	7,651	2,001	26
East Gulf			
Forest Service	42,296	11,280	27
SCS	33,706	4,346	13
Commerce	7,229	3,218	45
Central Gulf			
Forest Service	51,237	13,501	26
SCS	45,842	5,549	12
Commerce	8,156	3,453	42
West Gulf			
Forest Service	64,632	39,075	61
SCS	40,838	10,754	26
Commerce	9,731	6,703	69

with Forest Service estimates the highest at 100 million acres. This estimate include all classes of forest owners, and both non-commercial and commercial forest. The Forest Service estimate contrasts greatly with the Census of Agriculture value of 26 million acres which was made with substantial limitations on ownership.

The information presented in Table 2.3 indicates that ownership class is an important factor in the use of forest for livestock grazing. (There are four ownership classes: public, forest industry, farmer, and other.) Farmers in all geographical sections of the region graze livestock on a higher percentage of their forest land than other classes of owners. Also the Forest Service is mandated by law to manage the lands under its administration for multiple-use. Consequently, one would expect a large percentage of the National Forest System to be grazed. This tends to be true. For example, 36 million acres (about 53%) of the National Forest lands in the Rocky Mountains are grazed; 4.5 million acres (37%) of the Southern National Forest System are grazed. In contrast, only 25,000 acres, or 0.2% of the National Forest System, are grazed in the Northern region (34).

There is also considerable variation between the different regions and sections in the Eastern U.S. in the percentage of forest area grazed. These variations are, in part, due to regional differences in beef cattle numbers as indicated in Table 2.4. Nearly a third of the nations' beef cow herd is found in the four West Gulf States and Missouri while less than 2% is found in the Northeastern States. Fewer cattle numbers may be one factor in lower demand for woodland grazing in the Northern States; however, as will be discussed later, history of use, economics and ecology are also important factors.

Despite a willingness on the part of farmers to graze their livestock on forested areas, the number of acres being grazed has dropped in recent years. But, the data summarized in Table 2.5 indicates that this is not due to a decline in the use of farm forest for grazing. The Soil

Table 2.4. Cows and Heifers That Have Calved Located in the Eastern United States, January 1, 1979; Total National Herd Was 36,989,000. Source: "1979 Agricultural Statistics," Table 451, by USDA.

Region and Section	Beef Cows (000's)	% of National Beef Cow Herd	Region and Section	Beef Cows (000's)	% of National Beef Cow Herd
Northern Region	8,149	22.0	Southern Region**	7,768	21.0
New England	42	0.1	South Atlantic	1,244	3.4
Middle Atlantic	556	1.5	East Gulf	1,880	5.1
Lake States	896	2.4	Central Gulf	2,901	7.8
Central*	6,655	18.0	West Gulf (Part-AR, LA)	1,743	4.7
			West Gulf (Part-TX, OK)	8,028	21.7

* Includes MO with 6.2% of herd.

** Does not include OK, TX.

Table 2.5. Percentage of Farmer-Owned Forest Grazed by Livestock in 1959, 1964, 1969, and 1974. These Percentages were Calculated From Data Contained in Table 1, Chapter IV of the Census of Agriculture, U.S. Dept. of Commerce. The Percentage for 1959 and 1964 and those for 1969 and 1974 are not Directly Comparable Because of a Change in Reporting Procedures. The 1959 and 1964 Percentages are for All Farmer-Owned Forest While the 1969 and 1974 Percentages are Only for Those Farms with Sales Greater Than $2,500.

	Year			
Section and State	1959	1964	1969	1974
New England				
CT	26	24	31	29
ME	10	9	21	14
MA	20	21	30	18
NH	21	19	23	23
RI	13	12	28	22
VT	41	35	37	34
Middle Atlantic				
DE	3	5	18	13
MD	14	14	24	19
NJ	10	10	17	20
NY	32	30	34	30
PA	23	22	30	24
WV	39	39	41	37
Lake States				
MI	40	37	34	28
MN	62	62	59	53
WI	57	55	53	46
Central				
IL	57	56	52	47
IN	47	43	42	38
IA	79	78	75	68
KY	31	34	41	40
MO	69	71	62	61
OH	42	39	38	33
South Atlantic				
NC	13	14	24	22
SC	21	21	27	30
VA	20	23	31	28
East Gulf				
FL	76	76	69	70
GA	30	28	30	30
Central Gulf				
AL	42	41	38	37
MS	55	56	50	48
TN	33	36	41	42
West Gulf				
AR	53	59	54	50
LA	54	58	47	44
OK	88	90	83	72
TX	92	93	87	81

Conservation Service's Conservation Needs Inventory (CNI) of 1967 estimated that over 80 million acres of forest land in the East were being grazed. But the 1977 National Resources Inventory (NRI) by the same agency estimated that only 36 million acres were being grazed. The decline is not due to an increasing unwillingness by farmers to graze their woodlands; rather, it is due in a large part to changing patterns of ownership.

During the past 25 years, the amount of forested land owned by farmers dropped by 35%, but the forested area of the East remained constant (Table 2.6). Nearly 55 million acres of forested land passed from farmers' hands. Some forested land was converted to other farm uses; however, much of it went into the ownership class of "other". ("Other" includes all private holdings other than public, corporate, forest industry or farm lands (35).)

In summary, the Forest Service estimates that much of the Eastern forest is potential native grazing land, particularly under intensive management. It also estimates that a substantial amount of forage could be produced. However, these are only estimates. Forage production data from research and controlled livestock management studies are lacking for many of the Eastern PNC's.

Three Federal agencies conduct some inventories of livestock grazing in forested land but the information tends to be limited to the number of acres grazed. Information is lacking on management systems, specific forest communities grazed and forage use. However, it is clear that farmers frequently graze the livestock in the forest even though the number of woodland acres they own continues to decline.

The statistics from these inventories leave more questions unanswered than are answered. The data suggests some trends and patterns of use, but offer no explanation as to why. Fortunately the history of livestock grazing in the East helps explain some of these patterns and trends.

Table 2.6. Area, Including Percentages of Change Over Time, of Commercial Timberland in the Eastern United States, by ownership, region and section, and for the years 1952 and 1977. Source: Adopted From Table 2, "Forest Statistics of the U.S., 1977," Forest Service, USDA, 1978.

Region and Section	1952		1977		% Change in Forest Area of all Ownerships 1952-1977	% Change i Forest Are in Farm Ownership 1952-1977
	All Ownerships (000's of Acres)	Farm Ownerships (000's of Acres)	All Ownerships (000's of Acres)	Farm Ownerships (000's of Acres)		
Northern Region	167,768	64,567	169,353	44,431	1	-31
New England	30,936	7,842	31,015	2,391	0.3	-70
Middle Atlantic	42,099	15,114	48,215	10,013	16	-34
Lake States	51,838	14,227	49,356	11,345	-5	-20
Central States	42,895	27,384	40,767	20,682	-5	-24
Southern Region	192,083	91,312	188,433	57,217	-2	-37
South Atlantic	46,963	31,937	47,677	19,016	1.5	-40
East Gulf	42,104	23,134	40,142	11,006	-5	-52
Central Gulf	49,497	21,198	51,045	18,016	3	-15
West Gulf	53,519	15,042	49,569	9,179	-7	-39
TOTAL	359,851	155,879	357,786	101,648	-0.6	-35

III. HISTORY OF THE EASTERN GRAZING LANDS

Eastern Grazing Lands Prior to Colonial Settlement

Some of the finest grazing lands to be found anywhere in the world were located in the Eastern United States at the beginning of European settlement. Early accounts report a land much different than we know today.

Natural pine stands of the Southern forest were open, sparsely-stocked with trees and had little shrub development. Settlers reported forests "so open that wagons can be driven through them almost anywhere"(40). Other accounts were similar (44):

- DeSoto traveled much of the South in the 1540s and made numerous references to the cleared land and open forests.
- Woodward described the interior of Georgia in 1674 as "a pleasant and fruitful country, the woods being so clear of coppice and underbrush that a man could ride his horse a hunting."
- William Bartram referred many times about his Southern travels in the 1770s to the "open airy groves of superb pines," to "extensive old fields," to "grand high forest" and to "level green plains."
- DuPratz explored both sides of the high lands along the Mississippi River from the coast to the Ohio and Arkansas and wrote, "all these high lands are generally meadows and forest of tall trees, with grass up to the knee."
- Foote reported "vast prairies" and "extensive tracts covered only with grass" on the North Carolina and Virginia Piedmont and in the Appalachians of Tennessee.
- Lederer's accounts of Virginia and North Carolina state that the Piedmont "by the industry of Indians was very open and clear of wood."
- DuPratz and several others across the South, said that the Indians regularly set fires to facilitate travel and improve pasturage for "herds of all creatures."

- Hansbrough (44) has said, "the burning of the forests and meadows by Indians was not wantonly destructive but was rather a method of maintaining a balance in the forest favorable to their economy. Burning was primitive management of a food resource." Fire-agriculture appears to have been the norm in the South.

Fire, both natural and set by Native Americans, appears to have had an important role in maintaining several forest types: Douglas fir and Western white pine in the West, Eastern white pine in New England and Pennsylvania, pitch-shortleaf pine in New Jersey, and longleaf and loblolly pine in the South. Fire was also important in maintaining the prairies of the Mid-West.

It would be a number of years before the Europeans would reach the finest grazing lands of North America, the tall grass prairie which extended from Ohio to the Great Plains. These vast grasslands were the most productive of any of the American range (45), and fire is thought to have been important to its maintenance (4)(18).

Today, there is little to remind us of what once was our greatest range resource except that Illinois is nicknamed the "Prairie State." The bluestem grasses of the prairie were replaced by the grasses of man: corn and wheat.

European Settlement and Early Use of the Grazing Resource

The Spanish brought the first livestock into what is now the United States. Ponce De Leon brought cattle on his second expedition in 1521 (43). During that same century, DeSoto and LaSalle explored the prairies and savannahs of the Ozarks. They referred to the land as rolling grasslands with herds of buffalo, and found ample forage for their horses, mules and oxen (13). By 1650 Spanish "ranchos" were established in northern Florida (43).

Spanish colonies in the Gulf Coast did not persist but their cattle were to spread over much of the South (19). The Spanish cattle were probably Andalusian, and they were also brought into country by the British. The British found it easier to get cattle from the West Indies so early settlements in Virginia brought in Spanish cattle breeds. It was these cattle that introduced cattle tick fever to the Southeast. After the American Revolution, small numbers of dairy cattle became available. Crosses between the family milk cow and the resident cattle improved the line and produced an animal that would be important to the Southern cattle industry until World War II (38).

Cattle became important to the South, both as food and draft animals, with the growth of settlements and large plantations. The Civil War resulted in much of the land being fragmented and reverting back to timber. The cattle herds were largely decimated. After the war the Southern cattle industry was mainly confined to the "piney woods" of Florida and the Coastal Plain (19).

Today we know the piney woods as the longleaf/slash pine forest. This is a relatively open pine forest that lacks much of the hardwood midstory found in some of the forest types to the North. Consequently, it affords the best opportunities for range grazing in the region. Even so, the piney woods are a harsh environment for livestock and it is here that the southern "scrub cow", descendant of the Spanish cattle, came into its own.

The scrub cow was small with steers weighing only 400-500 pounds. The meat was of poor quality and the animal was said to be of the "4-H" type: nothing but hide, hair, hoofs, and horns. However, one thing could be said for the scrub cow, "even though she apparently was a regression in cattle type, she had one overwhelmingly important trait: she could survive..." (38).

The scrub cow was a hardy animal resulting from tough natural survival and selection processes. She was an excellent forager who could travel great distances and was a good mother capable of withstanding heat and drought, insects, poor forage quality; but most of all, she was resistant to cattle tick fever. Though much maligned as a meat animal, the scrub cow was adequate for the local market and the main export market in Cuba (38).

The settlement of the hardwood forests of the North was basically a 200 year struggle by man to clear the land for crops and pasture. The hills and valleys of the North were covered with magnificant forest which were cleared with oxen, mules, and horses for subsistence farms. Steepness meant little as long as the soil was fertile (8). In time, settlement moved beyond the Appalachians into the prairies of the Mid-West.

The prairies proved ideal for early agriculture. The prairie forage was in demand for hay to support livestock for food and animal power for transportation and tillage. The land produced abundant crops and the population grew rapidly. The agricultural and industrial growth in the Mid-West would greatly influence the development of the grazing lands of the Ozarks.

Early settlers in the Ozarks found large fairly open oak woodlands and prairies with abundant bluestem grasses, particularly on dryer sites (16). Settlers found stock raising the most profitable occupation as settlement began in earnest in the 1830s. Poor roads and long distances to markets made cattle the only cash crop since they could be driven to market (23). With the growth of markets in the Mid-West, the Ozarks would become a major ranching region.

Ranching in the Ozarks had all the requirements for success: high production of natural forage, cheap land, closeness to markets, abundant water and mild winters (20). Stock raising was encouraged in a Missouri handbook in 1881:

> Not another county in the state offers such inducements to stock growers as these hills and uplands. They are covered with a luxurious growth of grass, fine and nutritious, on which stock can be kept at least 9 months of the year without any other food - sheep, cattle, horses, mules, and hogs do as well here as they do on the famous bluegrass regions of central Missouri (23).

A later writer wrote of the settlers:

> They had an abundance of horses, cows, and hogs which all run at large, receiving almost no attention. The farmer encloses no meadows, or pastures - the only land fenced is that from which stock are excluded for growing small crops. Perhaps there is no country in the world where stock can be raised with so little trouble and expense (23).

Native grazing lands played an important role in the settlement of the Eastern United States. The forests and prairies provided inexpensive forage to support livestock to meet local needs for food, transportation, and animal power for tillage. In a few locations (the Ozarks and Florida), there was sufficient open range and marketing opportunities for a ranching industry to develop. But by the late 1800s, the picture would begin to rapidly change.

The Eastern Grazing Lands as Open Range: 1890s to 1930s

In the late 1800s timber harvesting became big business in the South and had major impacts on cattle production. By 1921, over 100,000,000 million acres of land in the South had been clear-cut of its timber. Since the land was owned by the lumbermen, whose only interest was timber, it remained as wood crews left it -- covered with stumps and strewn with crowns, unuseable logs and small trees. This blight would ultimately cover 250,000,000 acres in the Southern Coastal Plain. An area the size of Georgia, Alabama, and Mississippi combined (46).

The great timber harvests were not limited to the Coastal Plain. It is estimated that altogether 350,000,000 acres were cut in the South (19). The vast pine forests of the Great Lake States were also cut (12).

The cut-over land was a by-product of lumbering and no plans were made for its future use. With the end of the timber in sight, increasing taxes on non-productive land, and no market for the oversupply of such land, the land was left to revert to the state for back taxes (46).

The only useable resource on the cut-over land was forage and the land became open range. Everywhere the story was the same. The longleaf pine failed to reproduce under the combined pressure of indescriminate burning, hog-rooting and brown-spot needle disease (15). When the pine was cut in Southern Missouri, fires became frequent and cattle and hogs ranged unrestricted (11). The cut-over lands in Michigan were frequently burned and hardwoods soon dominated and large deer herds developed (12). Cattle numbers increased.

Burning was the management tool of the Southern forest range. Fires were set to control brush, kill insects, and to "freshen" the range, i.e., clear away the standing dead grass from last year's growth and promote early spring growth. Cattle were stocked at a rate of 10 acres per cow and management continued to be "survival of the fittest" (19). Forage quality throughout the Eastern native grazing lands is highly seasonal and is not adequate for the winter so supplements are required (19, 23, 37, 47). Yet no supplements were provided during these years. The result was that only the small scrub cow could survive and calved every 2 to 3 years with many calves failing to survive. It took 3-5 years to get steers to a weight of 600-700 pounds (19). With time, even the native grasses began to be depleted by overgrazing and uncontrolled burning.

The utilization of native grazing lands was also undergoing changes further north in the hardwood forests of the Appalachians and Mid-West.

Much of the Appalachians had been cleared of trees for subsistence farming. By the 1930s, mechanization of farming and industrialization of the South began to put an end to this farming. Some land reverted to woodlands as families left for jobs in industry. But many tracts were sold to valley-dwelling cattle farmers who used the abandoned farms for summer grazing.

Hand mowing and shrubbing maintained the area as grasslands, but as holdings became larger and labor more expensive, hand control was no longer possible. Farmers soon learned that close grazing in the early spring would keep down trees. However, the tall native grasses gave way to bluegrass on the better sites and weeds on the poorer. Erosion increased as a result (8).

The internal combustion engine changed the role of native grazing lands in the Mid-West. Until the mid-1920s, prairie hay was still in considerable demand but demand quickly dropped with the growing use of the automobile and farm tractor. The tractor could also be used to quickly break the prairie. Farmers could now cultivate expanding fields of crops. By mid-century the prairie had largely vanished (1).

As the demand for grains increased and much of the pasture land was plowed, the farmers began to turn to the woodlands as a source of grazing. Heavy and continued overstocking had disastrous effects on the forage and on tree growth and regeneration. Erosion also increased (48).

By the 1920s and early 1930s, the nation became increasingly concerned over land use, particular the cut-over lands in the South. Acts were past establishing the National Forest System in the South. Research began to look at the interactions between forestry and livestock. It was at this time that the future use of forest land for grazing would take two different tracks. Research would support livestock grazing on the Southern pines, but would result in opposition to grazing on Northern hardwoods.

Recent History of Grazing Lands in the Southern States

Government interest in developing livestock grazing in the South began in April, 1917 at the "Cut-Over Land Conference of the South" at New Orleans. More than 400 large landowners and State and Federal experts were present. The consensus of opinion was that the utilization of the lands in the near future depended on livestock grazing. Between 1917 and 1920, the number of cattle in the Coastal Plain increased from 3.7 million to 4.7 million with an average value of $25.77 per head. The region had about 11% of the U.S. herd but the herd only represented 6% of total value. The quality and size of the Southern cow had to be improved (46).

In the summer of 1917, the USDA in cooperation with Mississippi established a branch beef cattle experiment station at Collins, Mississippi to find practical ways to grow beef on cut-over pine lands. This station worked on problems of cattle improvement, improving pasture, winter feeds, diseases, and pest control, water supply, and markets (46). The pioneer work illustrating the opportunities to combine cattle raising with tree growing was done on the longleaf/slash pine forest (6).

The U.S. Forest Service initiated research across the South to coordinate forestry, animal husbandry and improved pasture. Such research started in Georgia in 1939, North Carolina in 1943, and Louisiana in 1944 (6). Solutions were found for many of the serious technical problems of raising cattle and pines on the Coastal Plain. However, a number of social and economic problems remained.

Most of the technical inovations required cattlemen to control the grazing land they used. Pure bred bulls could greatly improve performance particularly when combined with the use of supplemental winter feed or pasture. Calf crops of 85-90% and weaning weights of 400-500 pounds are possible (19). With proper stocking rates and winter supplements, grazing of pine trees for winter protein is greatly reduced (37). Cattle tick fever could be eradicated to permit the use of pure bred bulls if adequate quarantine zones are established (38). All of these practices required that the range be fenced so stocking rates and breeding are controlled; other cattle can not eat expensive supplements; and diseased animals are kept out.

More intensive management of the Southern cattle industry required two things the cattlement often lacked; ownership of the land and money for investments. Fencing, essential to the emergence of closed-pasture grazing, required legal sanction and a clear title to the land. Selling off tax-delinquent lands by the States was a major step in giving ranchers ownership of the land. The problem of investment money had to wait for the development of national markets for Southern beef and that came with World War II (38).

The Southern industry flourished after World War II through the widespread development of closed-pasture systems on improved pasture -- not on the forest range. Several factors brought about this changing pattern of land use. Large acreages of cut-over land were replanted in pines as prices for timber increased; simultaneously millions of acres of margional cropland were abandoned as subsistence agriculture came to an end. Cheap fertilizer, the availability of improved varieties of grasses, improved livestock and an expanding cattle market made it economical for much of this old cropland to be put into improved pasture. Even when it was not economical to have improved pastures, government programs provided subsidies to promote conservation through pasture establishment (8). Ample land for pastures and forests made it easier to manage for wood products and cattle separately even though it had been demonstrated that these products were compatible (49).

Recent History of Grazing Lands in the Northern States

Research for livestock grazing in Eastern hardwood forests started about 10 years after the first work in the cut-over lands of the South; however, the hardwood research took place under a very different philosophy. In the Southern pines, cattle were seen as an opportunity to bring land back into production. But in the Northern hardwoods, woodland grazing was observed to be damaging the forest so research was oriented toward documenting livestock impacts.

Writings of the period reflect the unfavorable attitude toward hardwood grazing. Johnson, writing in the Journal of Forestry (50) said, "Obviously, woodland grazing does affect these [Southern Appalachian] forest resources as shown by the bare soil and the absence of ground vegetation and litter under hardwood stands where cattle have congregated." Hunt wrote, in the 1934 USDA Yearbook of Agriculture, "Continued grazing of woodlands has disastrous effect not only upon grass cover but also upon tree growth and regeneration. As a result of long-continued overgrazing in the Corn Belt, fully 50% of the farm woods are no longer capable of yielding forest products, and the majority are threatened with almost total extinction." USDA Leaflet No. 86, issued in 1933 and revised in 1951, states, "Grazing seriously damages trees of all ages. In general, a thrifty farm woods makes a poor pasture; if pastured, it soon becomes a poor woods. Timber, like a corn crop, needs some attention, and both need protection from livestock."

In the 1930s, nearly all of the research on the impacts of hardwood grazing was performed at the Purdue Agricultural Station and the Central States Forest Experiment Station. These studies supplemented field observations with grazing studies. In the 1940s, experimental watersheds to study grazing inpacts were established at the Coweeta Hydrologic Laboratory, in the mountains of western North Carolina.

The experimental work by Purdue and the Forest Service near Valparaiso, Indiana in 1931 sought to "determine whether the farm woods of the Corn Belt are capable of furnishing any material amount of forage under the conditions of very heavy overstocking which prevail throughout the region." A "rather open oak-hickory woodland" was divided into 3 tracts of 18, 12 and 6 acres each; three yearling steers were placed in each tract for 6 months from May through October. The cattle gained weight the first 3 months and then weights dropped sharply as all the forage was used. Each following year the situation got worse in terms of animal performance (48). These results are hardly surprising with such high livestock stocking rates.

Unfortunately, such overstocking appears to have been common on Mid-Western farm woodlands. Purdue staff members conducted 15 years of field observations and concluded that high stocking rates were preventing natural forest regeneration. High stocking rates of 10 head of cattle per 20 acres of woods would ultimately destroy the forest in a series of five stages over an undetermined length of time. However, the second stage was thought to require 20 to 40 years; also forests in this stage could be reestablished if grazing was stopped for 5 to 10 years (9).

Grazing experiments at the Coweeta Hydrologic Laboratory also sought to demonstrate that overstocking could be detrimental to the trees, cattle, and watershed. The experimental area was on a 145 acre mountainous watershed that was covered by a three-storied hardwood forest where "some grasses and legumes were present, particularly along old skid trails and in openings left by fallen trees." Six steers were placed in the area each year from May until September for 8 years. After the first year, most forage had been used, and in subsequent years, "cattle required supplemental feeding in order to have strength enough to range the area." (50)

In time the grazing area came to resemble "conditions commonly found on typical farm woodlots." Utilization of trees 15 feet or less in height was so complete that this class nearly disappeared. Trees up to 2.5 inches in diameter were ridden down and tops eaten (50). The close grazing resulted in soil compaction, loss of soil litter, and a quick decline in water infiltration and permeability rates. The soil water-storage capacity was reduced and an increase in volume and frequency of surface run-off resulted (8)(50).

The results of these experiments plus field observations led to a near-universal conclusion perhaps best stated by the title of USDA Leaflet No. 86: "Protect Hardwood Stands From Grazing." Ahlgren (10) in 1946 summed up the attitude and recommended course of action that continues to prevail in government and academia: Hardwood grazing is hardly worth-while economically and it will ultimately destroy the woods. The best program would be to convert a few acres of woodlands into pasture and fence the rest for wood products plus recreation and aesthetics.

However, Ahlgren realized the size of the problem. In the 1940s, more than half the farm woodlands was being grazed in the United States. About 6.5 million forest acres of Wisconsin was being grazed. Intensive woodland grazing was also common on the margins of the prairie of the Mid-West and in New England and parts of New York and Michigan (10).

Current Use of Native Grazing Lands in the Eastern United States

Data developed for this report indicates that most of the recommendations for forest grazing have gone unheeded on farm woodlands in both the Northern hardwoods and Southern pines. Tables 2.3 and 2.5 indicate that the acres of woodlands grazed have declined because of changes in ownership -- farmers continue to graze a high proportion of the woodlands they still own. Data in 3.1 and 3.2 indicates that management of farm woodland grazing still has room for improvement.

Table 3.1 is a summary of non-federally owned acres of forest being grazed and what percentages were thought to require conservation treatments in 1967 and 1977. Two types of conservation treatments were recommended. The first is to reduce or eliminate livestock grazing and the second is to maintain grazing but improve forage production. Several points should be noted:

- Between 1967 and 1977, the percentage of land requiring treatment declined slightly but is still high in both regions;

Table 3.1. Area of Forest Land in Eastern United States Being Grazed by Livestock Including Area Requiring Conservation Treatments. Sources: Derived from "Basic Statistics: 1977 National Resources Inventory (NRI), Revised February 1980," Soil Conservation Service, USDA and "USDA Statistical Bulletin No. 461, National Inventory of Soil and Water Conservation Needs, (CNI), 1967: Basic Statistics," Soil Conservation Service, USDA, January 1971.

	1967 CNI				1977 NRI			
		Acres of Grazed Forest Requiring Conservation Treatments				Acres of Grazed Forest Requiring Conservation Treatment		
Region and Section	Acres of Forest Grazed (000's)	Reduce or Eliminate Grazing (000's)	Improve Forage (000's)	% of Grazed Forest Land Requiring Conservation Treatment	Acres of Forest Grazed (000's)	Reduce or Eliminate Grazing (000's)	Improve Forage (000's)	% of Grazed Forest Land Requiring Conservation Treatment
Northern Region	20,501	17,203	2,020	94	13,130	8,236	3,533	90
New England	299	260	-0-	90	231	81	59	61
Middle Atlantic	2,239	2,085	-0-	93	1,870	1,418	210	87
Lake States	4,598	3,094	1,013	89	3,264	2,051	753	86
Central	13,365	11,764	1,007	96	7,765	4,686	2,511	93
Southern Region	60,565	15,402	34,137	82	22,967	6,081	10,239	71
South Atlantic	2,665	2,206	265	93	2,318	962	553	65
East Gulf	9,825	1,603	6,677	84	4,346	824	2,209	70
Central Gulf	9,951	3,736	4,121	79	5,549	2,283	1,400	66
West Gulf	38,124	7,857	23,074	81	10,754	2,012	6,077	75

Table 3.2. Non-Federal Lands in the Eastern U.S. by Land Capability Grouping, Land Use, and Estimated Average Annual Sheet and Sill Erosion for 1977. Geographical Regions Are Those Crop Production Regions As Defined By The S.C.S. Source: Table 172 "Basic Statistics, 1977 National Resources "Inventory (NRI)," Revised February 1980, Soil Conservation Service, USDA.

Region and Capability Groupings	Erosion (Ton/Acre) by Land Use					
	Ungrazed Forest	Grazed Forest	Cultivated	Hay	Pasture	Range
Northeast						
Classes I-IV	0.27	1.42	6.33	0.79	0.96	-
Classes V-VIII	0.54	4.60	11.75	1.27	3.79	-
Lake States						
Classes I-IV	0.06	1.41	2.81	0.54	0.82	0.05
Classes V-VIII	0.39	12.70	6.94	2.65	2.74	0.44
Corn Belt						
Classes I-IV	0.66	5.47	7.56	1.72	2.43	0.37
Classes V-VIII	1.94	11.42	29.60	4.20	9.18	-
Appalachian						
Classes I-IV	0.26	2.52	9.12	1.56	1.65	-
Classes V-VIII	1.90	7.26	46.13	8.06	10.65	-
Southeast						
Classes I-IV	0.16	0.53	6.95	0.38	0.47	0.27
Classes V-VIII	0.63	1.41	16.42	0.86	1.30	0.36
Delta						
Classes I-IV	0.18	1.56	6.86	0.78	1.33	1.90
Classes V-VIII	0.99	8.54	28.35	5.09	9.20	4.51
Southern Plains						
Classes I-IV	0.10	0.45	3.41	0.76	0.97	1.00
Classes V-VIII	0.71	1.62	4.58	0.44	2.15	5.22

- Reducing or eliminating grazing is the most recommended practice in the Northern region while increasing forage production is more often recommended in the South;
- The sharp drop in the number of acres of woodlands being grazed in the West Gulf section of the South is due, in large part, to a change in classification of land types as discussed earlier. Marginal forest lands were reclassified as range.

Tables 3.2 and 3.3 contain summaries of erosion by land capability class and land use, and the area in each land capability class being grazed. (A summary of the definitions of the various land capability classes is given in Appendix 3, along with a list of the states in each section.) This information indicates that a considerable amount of erosion may be resulting from livestock grazing in woodlands, particularly on the more marginal lands (classes V-VIII). The conservation treatments recommended in Table 3.1 are largely directed at reducing these levels of erosion by maintaining adequate ground cover. Several other points should be noted:

- Grazing on woodlands is thought to increase erosion by at least an order of magnitude except in the Southern Plains, Southeast (classes I-IV), and Appalachian (classes V-VIII) Regions;
- Woodland grazing generally results in more erosion than converting the land into pastures but intensive management of the land for hay production produces even less erosion;
- Woodlands and woodland grazing are common on all land capability classes except class VIII.

The data presented in this report and the opinions of members of the various land management professions (47) suggest that woodland grazing is still, by and large, conducted with little management or awareness of its impacts. Campbell (6) in 1946 noted that a large portion of the cattle, sheep, and hogs in the South grazed the forest range at least part of the year. Range management was primitive and livestock production was low. But the information was available to solve these problems, particularly in the South. The question was how to get the information out to more than a million small farm owners?

Table 3.3. Area of Forestland (Non-Federal) by Land Capability Classes and Use For Livestock Grazing in 1977 for Eastern Crop Production Regions as Defined by the SCS. Source: Table 5a, "Basic Statistics, 1977 National Resources Inventory (NRI)," Revised February 1980, Soil Conservation Service, USDA.

Region	Forested Land Area By Land Capability Class (000's Acres)						
	I-III	IV	V	VI	VII	VIII	Total
Northeast							
Grazed	489	248	53	228	277	15	1,310
Ungrazed	13,297	5,250	974	22,012	19,191	1,130	61,854
Lake States							
Grazed	1,358	765	64	470	607	0	3,264
Ungrazed	13,771	12,700	1,519	6,808	4,015	311	39,124
Corn Belt							
Grazed	1,760	1,167	66	1,228	2,119	0	6,340
Ungrazed	6,716	3,415	142	3,135	4,991	7	18,406
Appalachian							
Grazed	1,232	712	29	1,266	2,407	0	5,646
Ungrazed	16,363	6,742	1,083	8,166	23,740	397	56,491
Southeast							
Grazed	1,736	1,394	655	569	734	0	5,088
Ungrazed	19,921	14,203	5,110	9,475	10,439	32	59,180
Delta States							
Grazed	3,242	819	840	1,293	1,677	0	7,871
Ungrazed	13,227	4,533	4,337	4,138	6,930	43	33,208
Southern Plains							
Grazed	2,859	1,185	902	1,521	1,748	0	8,215
Ungrazed	2,069	855	553	1,436	1,043	0	5,956

Thirty-five years later that question is still being asked; but a more important question is also being asked, "how do you motivate landowners to use the information once they receive it?" (47) Economics seems to be a key factor.

IV. ECONOMIC CONSIDERATIONS

Producing Livestock on Woodlands

Any real understanding of the use and management of forested grazing land requires that two questions be answered. First, why do farmers continue to graze forested land in a largely opportunistic fashion and not manage the land within its capabilities? Secondly, why has so much of the farmer-owned forest been sold or converted to other land uses? The answer to both of these questions is related, at least in part, to economics.

Estimates of the amount or value of livestock production from forest livestock grazing are generally lacking for the Eastern U.S. However, some work is being done on a few forest-types in the South (51). The data base generated by the Forest Service for the recent RPA Assessment does contain some estimates of the cost of managing forest land under varying levels of intensity and expected forage output. (This data base was discussed in Section II of this report.) With some fairly heroic assumptions, this data can be used to make a crude estimate of the value of livestock grazing on Eastern forests.

The RPA-related data base estimates investment costs (in 1976 values) per acre under several different levels of management for each of the Potential Natural Communities (PNCs) found in the East. However, inventories of grazing data are reported as number of acres grazed and not by PNC. Therefore, it will be assumed that each PNC is grazed solely on its availability. That is, if a PNC represents 5% of the Eastern forest area, then 5% of the acres of grazed woodland will be in this PNC. There is evidence that forest grazing is concentrated in geographical areas so this assumption is not completely valid (52). However, under this assumption the following estimates were made.

Northern Region	AUM/acre	Cost/acre
Extensive Management	0.04	$ 0.68
Intensive Management	0.63	$ 2.57
Southern Region		
Extensive Management	0.07	$ 0.49
Intensive Management	0.80	$ 2.52

An AUM is an Animal Unit Month; the amount of forage required to support a cow and her calf for one month. There are 12 AUMs in an AU (Animal Unit Year). The cost data is the cost of managing the land for forage production.

The SCS estimates of the number of acres of forestland being grazed on non-Federal land in 1977 can be used; however, the level of management for each acre of grazed forest is unknown. The Forest Service has estimated that more than half of the AUs produced in the Eastern U.S. result from extensive management (Table 4.1 was used for this estimate by combining acre totals in "some management" and "extensive management"). Since production from the various levels of intensive management are at least an order of magnitude higher than under extensive management, at least 10 acres would have to be managed extensively to equal one intensively managed acre. Therefore, at least 90% of the grazed forest land is being extensively managed. This finding is in general agreement with the data on conservation needs cited in Section III of this paper.

The following estimates take two options into account: that the land is all under extensive management or all under intensive management. Readers may also consider some "inbetween cases" where there is a mix of intensive and extensive management. (All dollar amounts are 1976 values.)

Table 4.1. Production of Range and Forest Range Livestock Grazing in the 48 Contiguous States By Ecosystem Groups and Animal Unit Years (AU's) of Forage. Source: "An Assessment of the Forest and Range Land Situation in the United States," Table 5.8. U.S. Forest Service, USDA, January 1980.

		Management Level				
Ecosystem Groups	Some Livestock	Extensive Management	Intensive Management	Livestock Maximized	Exploitative Grazing	Total Production (And % Of Total By Eco-Group)
Grasslands						
AU's	499	4,439	2,243	2,469	1,715	11,365
%	4	39	20	22	15	(64)
Shrublands						
AU's	393	1,065	1,163	453	1,391	4,464
%	9	24	26	10	31	(25)
Western Forest						
AU's	172	126	54	57	25	434
%	40	29	12	13	6	(3)
Eastern Forest						
AU's	416	389	267	199	131	1,402
%	30	27	19	14	9	(8)
Total, Contiguous States						
AU's	1,479	6,020	3,727	3,178	3,262	17,666
%	8	34	21	18	19	(100)

Northern Region	Acres Grazed	Total AUs	Forage Mgt. Costs
Extensive Management	13,130,000	43,767	$ 8,928,400
Intensive Management	13,130,000	689,325	$33,744,100
Southern Region			
Extensive Management	22,967,000	133,974	$11,253,830
Intensive Management	22,967,000	1,531,133	$57,876,840

The next set of assumptions to be developed relate to converting the forage into a marketable livestock product. Range is usually used for cow-calf operations so the main output is a calf. It is assumed that all of the forage will be used for a year-round cow herd that would produce a 70% calf crop that will go to market at an average weight of 375 pounds. In 1976, the average price for a calf was $0.34 a pound. Therefore:

Northern Region	Calf Crop	Total Gross Earnings	Gross Earning Per Acre Grazed
Extensive Management	30,637	$ 3,906,205	$ 0.30
Intensive Management	482,527	$ 61,522,256	$ 4.69
Southern Region			
Extensive Management	93,782	$ 11,957,180	$ 0.52
Intensive Management	1,071,793	$136,653,620	$ 5.95

Since forage management costs exceed gross earnings, grazing livestock in woodlands under extensive use would result in an economic loss. A small profit results from intensive management if other input costs are not considered.

Why does woodland grazing continue if it is not economical? The answer seems to be that woodland grazing is mainly opportunistic and there are few management inputs, particularly on open range. In the 1948 Yearbook of Agriculture (53), Cassady wrote, "The cheapest feed for livestock in the South is obtained from native grasses on some 200 million acres of forest land. Since early Colonial times the clearings and cut-over forests have provided free grazing." Herring (23) observed that woodland grazing in Missouri was a cheap way to make a living off the land with very little effort or time involved, and as long as there was free range, people would take advantage. Open range grazing may produce low returns, but with no inputs, these returns are mostly profit.

Open range has a long history in the South, and is a tradition that is taking a long time to die. Mealor and Prunty (38) have written that the saga of open range in the West is a part of our national folklore, but the persistence of open range in the South is not well known. Open range grazing continued in Florida from 1830 till World War II. Fencing was opposed by Florida cattlemen through their Cattleman's Association during the 1920s and 1930s. A state-wide fencing law was not past until 1949. Open range in other states continued even longer.

Local elections decided whether the range and forest in a given township or county was to be open or closed under Missouri Stock Law. In 1951 there were still 96 open townships. Open range was often overgrazed, rarely improved, repeatedly burned and forest management almost impossible. Why did the people vote to keep open range when nearly all the land was in private ownership? In many counties absentee owners and corporations with few votes, owned much of the land. The local farmers found it to their economic advantage to vote for free and unrestricted land use since they could now graze on an area much larger than their own holdings (54).

Improved forest management was a major factor in closing the range in the forests of the South in the 1950s; however, the tradition of open range continues. The timber industry set out to manage the land and invested large amounts in planting trees. Fencing and fire prevention were seen as essential tools to protect the young pine plantations. The use of these tools often led to conflict. Open-range cattlemen had traditionally set fires to keep the land clear and did not want fences which prevent free movement of animals to the forage. Forest arson and fence cutting became common in some parts of the South (55)(56).

The history of grazing livestock in the Northern hardwoods is less colorful than that of the Southern pines, but the economics seems to be similar. Many farms have some acres of woodlands along with cropland and some pasture; these woodlands often becomes part of the farm production system when livestock are part of the operation. Woodlands provide spring and summer grazing -- little forage may be provided but is of low cost. The woods also can be used as a holding area when hay is being harvested, or prior to turning the cattle out on recently harvested croplands. Finally, the trees provide shelter for animals and serve as "outdoor barns." This last use can really have serious impacts when large numbers of animals concentrate in a small area and serious soil erosion results (57).

In summary, many farmers both in the North and South, have viewed woodland forage as a free good, and more importantly, they have seen few other uses for woodlands that offered a better opportunity for income. A review of production and marketing of wood products seems to indicate their limited appeal to the farming sector.

Wood Products From Farm Woodlands

An argument against forest grazing is that it reduces the production of wood products. This is particularly true for hardwoods. Farmers would be expected to shift from woodland grazing to forest management if more money could be made.

The data in Table 4.2 needs to be interpreted with care, but it does indicate that farm earnings from wood products are low. A small percentage of farms market wood products, but those that do may make reasonable earnings. The average values make interpretation difficult, however. For example, a farm making $2,000 each year by selling wood products would be one thing, but a farm making $2,000 only once every 35 years at the end of a long timber rotation would be something else. Such variation is possible because wood products include everything

Table 4.2. Characteristics Of Farmer-Owned Forested Land in 1974 Including Ownership Patterns and Incomes From Sale of Wood Products. Source: Derived From Tables 1 and 3, Chapter IV of the Census of Agriculture, U.S. Department of Commerce.

Region and Section	Land in Farm Ownership (000's Acres)	% of Farm Land In Forest	% of Farms With Forest Land	% of Farms With Forest Land Marketing Wood Products	Gross Earnings by Farms Marketing Wood Products (000's Dollars)	Average Earnings Per Farm Marketing Wood Products (Dollars)	Average Earnings Per Acre of Farm Forest (Dollars)
Northern Region	225,134	14	49	6.3	56,732	1782.23	1.87
New England	4,933	42	71	22.2	7,888	2172.40	3.84
Middle Atlantic	25,317	23	64	7.5	14,122	2117.56	2.46
Lake States	56,061	14	51	6.2	13,629	1704.69	1.79
Central States	138,823	11	43	4.9	21,093	1558.17	1.40
Southern Region (Excluding TX, OK)	117,206	28	62	9.8	131,958	4234.31	3.98
South Atlantic	27,098	35	64	7.9	36,025	4148.91	3.78
East Gulf	27,077	31	53	12.9	44,836	7535.46	5.37
Central Gulf	39,256	35	61	9.8	38,697	3165.40	3.46
West Gulf (AR, LA)	23,775	17	74	11.4	12,400	2879.70	3.02
West Gulf (TX, OK)	167,267	5	23	5.4	7,804	2534.59	0.91

from pulp logs to firewood to naval stores to Christmas trees to saw logs to hardwoods suitable for expensive furniture. The range in amount and frequency of earnings may also be extreme within a region. But whatever the details, earnings from farmer-owned woodlands are, on the average, low on a per acre basis. If there is an opportunity, farmers don't seem to be developing it because of a number of factors.

Barriers to Better Forest Management on Farms

There is considerable concern nationally about the lack of forest management on farmer-owned woodlands. This problem is beyond the scope of this report but some of the reasons that farmers are not managing for wood products include:

- lack of awareness of financial opportunities in wood products;
- small woodland holdings not practical to manage;
- long rotations with poor cash flow and investment tied up for long periods;
- lack of management skills;
- no local markets;
- poor markets for many hardwood species;
- high risk;
- and tax policy.

Summary

Over 50 million acres of forested land have passed from farm ownership in the last 30 years. With increasing land values and higher taxes, farmers have often found that they can not afford to keep forested land for either woodland grazing or production of wood products. The future of these lands will depend upon how the mix of economic and social factors change the value that is placed on the various resources these forests can supply. Intensive management of forest lands for both wood products and livestock forage may make it economical to keep farm forests.

V. FUTURE CONSIDERATIONS FOR LIVESTOCK GRAZING ON EASTERN FORESTED LANDS

Evaluating Eastern Forested Grazing Lands as a Resource

Hansbrough (44) said, "Natural resources are used by man as the means of achieving certain goals. It is in this context that resources are man-made. The value of any resource is the function of the general economy of the people as well as other aspects of their culture. Thus, it is evident that resources are determined by the cultural context of a people and since culture changes, resources are always changing." He concluded, "...resources are man-made in that their utility is defined within the value orientation of the user."

Native grazing lands have been defined here as ecosystems that produce naturally occurring vegetation suitable for livestock grazing in an economically and environmentally sound manner. This definition reflects a set of cultural values that places environmental quality on an equal footing with economic viability. Such values are not universally held today, and certainly were not widely held in the past. Attempts to redefine the nation's goals for using its land base have led to disagreements over which criteria should be used to evaluate forest land grazing. As a result each of the various user groups has its own criteria for evaluating a potential resource.

Such alternative sets of criteria for evaluating forest land grazing have created conflicting views in the Eastern U.S. in classifying and using the land. This, in turn, results in practical problems in designing land use inventories. The lack of clear criteria for evaluating land uses also leads to political and legal conflicts.

Conflicts Between Livestock Producers and Foresters in the Eastern Forests

During the last 50 years, livestock grazing in the Eastern forests has not been acceptable to several land user groups and open conflicts have resulted. Foresters and cattlemen, in particular, have been frequent antagonists.

Modern forestry developed to protect the nation's forests and manage the land for a sustained yield of wood products. Exploitive woodland grazing resulted in serious damage to trees and was viewed as a problem. The solution was simple: Get the livestock out of the woods. Foresters argued that the farmers' forests were a valuable source of wood products and farmers could be best served economically and environmentally by establishing a few acres of pasture and protecting the woods from grazing. (Other solutions were considered, particularly in the Southern pine forests. Opportunities for integrating livestock grazing with pine production were identified but development of these opportunities has been limited.)

The farmer's attitude toward the forest is often very different from the forester's. Farming in the Eastern U.S. required the wholesale destruction of hundreds of millions of acres of forest. Much of the region's crop and pasture land was wrested from the forest with ax and mule, and muscle and fire. Wood lots were retained to provide the farm's needs for wood products and firewood. More recently, farmers depended less on their forests for wood products, and forest land has been converted to other uses where economically possible. Forest land still in farmer ownership is usually not managed for commercial timber production. In fact, many farmers continue to graze livestock at the expense of forest regeneration.

Farmers may lack the forester's reverence for trees, but many make up for it in their awe for cattle. Studies (42) in the Southeast on profit maximization of farms indicate that beef cows are not always competitive with other agricultural enterprises. Profit maximization is often not the major objective in farm economics. Accumulation of net worth, annual net income, leisure time and risk are important factors. However, there is also an important element of "conspicuous production" in having a beef cow herd. (Conspicuous production is defined as production associated with improvement of social status.)

The term "cattleman" is associated with a hundred years of tradition, advanture, and romance as witnessed in hundreds of books, movies and television series. Being a Cattleman associates a person with this tradition and in many peoples' eyes carries greater status than being a tree farmer or growing row crops. Consequently, having a few head of cows on the farm can increase the farmer's social status.

The forester or government agent who asks the farmer to get his cows out of the woods so an acorn can spend the next hundred years growing into a mighty oak will face an uphill battle. This is particularly true if the farm is short of grazing land which is often the case.

Management for a Single Dominant Land Use Reduces Conflict

Conflicts between forester and livestock producers started in the 1930s as foresters began to manage for timber growth. However, several factors alleviated the conflict except in Southern pine forests. Widespread availability of abandoned farmland and the development of technologies for intensive pasture and pine production were two such factors because they made it possible to practice land management for a single dominant-use.

Under single dominant-use management, land is intensively managed for one product, e.g., forage or pine trees for pulp and saw logs. Such management usually requires high technological inputs but results in high output per acre. Managing for only one product helps to maximize production of a product, simplifies management, and lowers investment costs. Separating land uses, such as pine production and livestock grazing, also reduces conflict as long as sufficient land is available for each of the producer group's needs.

Conditions for the intensive production of forage and pine were ideal after World War II. Unused cropland, particularly on marginal land, was converted into improved pastures and pine plantations with the newly available technologies that depended on cheap energy, and agricultural chemicals and fertilizers.

Farm Woodlands Decline in Value as a Resource

Farmer-owned woodlands declined in area as economics of forest ownership became less profitable. Hardwoods, in particular, were of little value for grazing or wood products. Many farm woodlands were cleared for crops and pasture. Other woodland acres were sold, and much of the forest that remained on the farm was not managed for a product (57).

Millions of acres of unmanaged forest land in the Eastern U.S. have helped to minimize social conflicts by providing forest land for wildlife, recreation and aesthetic values. Abundant land resources makes it possible for each user group to engage in intensive management for a single product without considering other land users. Unfortunately, the days of abundant unmanaged land are ending in the forested lands of the Eastern U.S. and land use conflicts are becoming more common.

Developing Land Shortages and Multiple-Use Management

Conflicts between the livestock and pine producers never completely stopped in the longleaf/slash pine forests of the Southern Coastal Plain. Cattlemen continued to seek livestock forage in the forests even with the advent of improved pasture. One result of this continuing forestry/livestock interaction was pressure to conduct multiple-use research to develop alternative production systems in which forestry and livestock could co-exist.

Under multiple-use land management, several uses are made of the land, either simultaneously or in close succession. For example, a land area is intensively managed to simultaneously produce forage for livestock and grow trees for wood products. Multiple-use management is common on public lands where a variety of demands are placed on a limited land base. This management approach will be required on more privately-owned lands in the future, particularly on forested lands which can supply so many different goods and services.

The multiple-use management approach to land use contrast sharply with single dominant-use management and often uses existing technologies much differently. Thus, the impacts of using technological inputs in a multiple-use framework may be very different than using the same inputs under single-use management. Field measurements are needed for an adequate understanding of multiple-use impacts in order to evaluate various production systems. The information base for conducting multiple-use management to integrate forage production and livestock grazing with other forest land uses is limited mostly to the longleaf/slash forest of the Southern Coastal Plain.

The U.S. Forest Service has conducted multiple-use research on forest livestock grazing since the 1940s. This research, combined with practical management demonstrations provided the basis for improved forest-livestock-forage interactions in longleaf/slash pine forests (47). However, many questions are still unanswered so research is continuing with emphasis on how livestock management interacts with other forest uses.

The strong research and demonstration programs in the longleaf/slash pine forest and portions of the Southern mixed pine/hardwood forest are in stark contrast to the programs for the rest of the Eastern forests.

Little has been done to develop livestock grazing technologies for these hardwood forests although some research has been done on big game grazing and its effects on hardwood growth.

One apparent reason for the lack of research on the hardwoods forest-types is that these lands are no longer producing products that are in great demand. Many of the valuable hardwood species suitable for harvest have been removed, and few landowners can justify the economics of the long rotation times required for hardwood growth. The market is limited for the less valuable hardwood species that remain. Furthermore, hardwood forests produce little forage for livestock and farmers can not afford to clear the unwanted trees to establish pasture. The same conditions that produce limited forage for livestock also produce limited forage for many game animals. Perhaps the only user groups that value the hardwood forests in their current condition are rural home owners and real estate developers.

Future Demands for Biomass From Hardwood Forests

Will society once again value the biomass produced on the hardwood forests as a resource? Changing consumer tastes combined with rising grain prices, are increasing the demand for forage-fed beef. Higher grain prices also create pressure to convert pasture land to cropland. Energy needs are making all sources of biomass, particularly wood, more valuable. A growing population and changing needs may force a re-evaluation of current management which is leaving the resource potential undeveloped on millions of acres of forested land.

Research and Educational Needs for Future Use of the Eastern Forests for Livestock Grazing

To rapidly expand production of wood and forage biomass in the Eastern forests in an environmentally safe manner, three obstacles must be overcome:

1. Multiple-use land management technologies must be made available to meet the needs of various types of land owners and to minimize conflict over land uses.

2. Current trends in forest land ownership appear to be unfavorable for expanding biomass production. Would the nation's long-term interests be better served by having the farming sector own large forest acreages? If so what can be done to reverse current trends where farmer-owned woodlands are being transfered to other owner groups?

3. Land managers (farmers, foresters, etc.) of private lands are accustomed to single dominant-use land management. Many must learn to practice multiple use management if their individual objectives and the nation's objectives are to be met.

Multiple-use management offers the best opportunity for overcoming these constraints. For example, there may be a substantial demand for wood biomass as an energy source as new technologies become available. Farmer-owned wood lands may be an excellent source of such biomass. But, history has shown that farmers have a limited interest in producing wood products even when potential economic returns are high. The reasons are many but two of the more basic are cash flow, and conficts with other farm activities such as raising cattle. Forestry production systems that enable the farmer to increase cattle production while increasing tree growth are more likely to be adopted than systems that promoted forestry over livestock. However, such multiple-use systems have not been developed for most forest-types.

Technologies for Multiple-Use Management of Forest Grazing

Multiple-use land management consists of integrating various land uses into an overall framework. Each land use is developed as a subsystem with technologies that permit it to be integrated into the overall system.

The technologies needed to develop the forage/livestock subsystem and integrate it into overall forest management can be grouped into three categories:

1. Technologies for managing livestock utilization of native forages must insure proper use of the vegetation so that 1) animal performance is adequate; 2) the vigor of the plants is maintained; and 3) other resources are not damaged. These technologies include grazing systems, controlling season of use, managing stocking rates, selection and mix of grazing animals, use of feed supplements, and construction of physical structure (fencing, water development, etc.).

2. Technologies for improving forage productivity and quality are frequently needed to increase output per acre for adequte economic returns, or to restore vegetation on damaged land. Technologies include seeding with improved plant species, fertilization, water development, use of mixtures of cool and warm season plant species as well as shade tolerant species in forests and the use of chemicals, fire and machines to control unwanted plant species.

3. Technologies for managing the impacts of the forage/livestock subsystems on other land uses (and vice versa) are required to reduce conflicts and maximize overall output of the mixtures of goods and services. Such technologies often involve tradeoffs between uses and depend on the judgement of the land manager. For example, the tree overstory limits light and water flow to the soil and forage production declines. Opening up the tree canopy will increase forage production but may reduce overall production of wood biomass. Success in selecting a technology to manage such interactions depends on the availability of knowledge about how each resource will respond, so that tradeoffs can be estimated and evaluated.

The level of development of these three categories of technologies for grazing livestock on the Eastern forest, varies from category to category, and from forest-type to forest-type. But in general, few technologies are well developed particularly for the hardwood forests.

Summary of the Eastern Forest as a Grazing Resource

The grazing potential of the Eastern forest appears to be a resource that has not been considered of sufficient value to develop and manage with appropriate technologies. Those technologies that have been designed for forage production in the region are based on a philosophy of single dominant-use whereby the forest is replaced by pasture. Farmers continue to graze their woodlands, but at a low level of management. Such extensive management of woodland grazing appears to be economically motivated, but is also environmentally destructive; however, few alternatives for intensive management have been identified and evaluated except in the Southern pine forest. Technologies are largely lacking for managing most Eastern forests for the simultaneous production of wood and forage. Until such technologies are available, the forest land owner will have little choice except to manage for wood products or clear the forest to establish pasture.

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APPENDIX I

The States, Sections, and Regions of the Eastern U.S. are defined for this report.

Northern Region

New England Section:	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.
Middle Atlantic Section:	Delaware, Maryland, New Jersey, New York, Pennsylvania, and West Virginia.
Lake States Section:	Michigan, Minnesota, and Wisconsin.
Central Section:	Illinois, Indiana, Iowa, Kentucky, Missouri, and Ohio.

Southern Region

South Atlantic Section:	North Carolina, South Carolina, and Virginia.
East Gulf Section:	Florida and Georgia.
Central Gulf Section:	Alabama, Mississippi, and Tennessee.
West Gulf Section:	Arkansas, Louisiana, Oklahoma, and Texas.

APPENDIX II

1. States and Sections of the Eastern U.S. as defined by the Soil Conservation Service.

Northeast Section:	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.
Lake States Section:	Michigan, Minnesota, and Wisconsin.
Corn Belt Section:	Illinois, Indiana, Iowa, Missouri, and Ohio.
Appalachian Section:	Kentucky, North Carolina, Tennessee, Virginia, West Virginia.
Southeast Section:	Alabama, Florida, Georgia, and South Carolina.
Delta States Section:	Arkansas, Louisiana, and Mississippi.
Southern Plains Section:	Oklahoma and Texas.

2. Soil Conservation Services' Land Capability Classification Classes:

Land Suited for Cultivation and Other Uses

Class I. Soils in Class I have few limitations that restrict their use. Soils in this class are suited to a wide range of plants and may be used safely for cultivated crops, pasture, woodland and wildlife.

Class II. Soils in Class II have some limitations that reduce the choice of plants or require moderate conservation practices. Soils in this class require careful soil management, including conservation practices, to prevent deterioration or to improve air and water relations when the soils are cultivated. The limitations are few and the practices are easy to apply. The soils may be used for cultivated crops, pasture, woodland, or for wildlife food and cover.

Class III. Soils in Class III have severe limitations that reduce the choice of plants or require special conservation practices or both. Soils in Class III have more restrictions than those in Class II, and when used for cultivated crops, the conservation practices are usually more difficult to apply and to maintain. They may be used for cultivated crops, pasture, woodland, or for wildlife food and cover.

Class IV. Soils in Class IV have very severe limitations that restrict the choice of plants, require very careful management, or both. The restrictions in use for these soils are greater than those in Class III, and the choice of plants is more limited. When these soils are cultivated, more careful management is required and conservation practices are more difficult to apply and maintain. Soils in Class IV may be used for crops, pasture, woodland, or for wildlife food and cover.

Land Limited in Use--Generally Not Suited for Cultivation

Class V. Soils in Class V have little or no erosion hazard, but have other limitations that are impractical to remove that limit their use largely to pasture, woodland or wildlife food and cover.

Class VI. Soils in Class VI have severe limitations that make them generally unsuited for cultivation and limit their use largely to pasture, woodland, or wildlife food and cover. Physical conditions of soils placed in Class VI are such that it is practical to apply pasture improvements, if needed, such as seeding, liming, fertilizing, and water control with contour furrows, drainage ditches, diversions, or water spreaders.

Class VII. Soils in Class VII have very severe limitations that make them unsuited for cultivation and that restrict their use largely to grazing, woodland or wildlife. Physical conditions of soils in Class VII are such that it is impractical to apply such pasture or range improvements as seeding, liming, fertilizing, and water control measures such as contour furrows, ditches, diversions, or water spreaders. They can be used safely for grazing or woodland or wildlife food and cover, or some combination of these under proper management.

Class VIII. Soils and landforms in Class VIII have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, water supply, or aesthetic purposes. Soils and landforms in Class VIII cannot be expected to return significant onsite benefits from management for crops, grasses, or trees, although benefits from wildlife use, watershed protection, or recreation may be possible.

Background Paper No. 4

INFLUENCES OF COMMODITY PROGRAMS
ON LONG-TERM LAND PRODUCTIVITY
(CONSERVATION)

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This background paper was prepared for the assessment "Impacts of Technology on U.S. Cropland and Rangeland Productivity." The views expressed are those of the author(s) and not necessarily those of OTA.

Although the preservation of the long-term productivity of America's farmland has consistently been a policy objective of federal commodity programs, the design and implementation of those programs have been much more directly influenced by short-term economic considerations.

Several features of these programs periodically have important effects on cropping patterns on many millions of acres of American farmland. In addition, gradual modifications of the programs have given greater emphasis to market-type mechanisms for determining land allocation, yet these mechanisms often do not account for long-term conservation costs. Should the incipient yield plateaus observed in recent years for major crops cause world demand for U.S. commodities to chronically outstrip our production, pressure on the land will certainly increase, and it may become necessary to more explicitly include conservation considerations in commodity program policy.

Indeed, commodity programs have been seen as an opportunity to promote the conservation of long-term land productivity, through systems of incentives or penalties that would link participation in the programs to conservation objectives. A number of proposals of this type have been examined in the Resource Conservation Act (RCA) process in recent years, by both the Department of Agriculture and the general public.

Yet in many respects the ways in which commodity programs, agricultural technology and economic developments have interacted to effect conservation are not well understood.

BACKGROUND

The conservation of land resources has been a secondary consideration in the design and implementation of federal commodity programs, the primary considerations having been to support farm prices and income, while minimizing federal expenditures and protecting consumers from excessive or abrupt price increases for food and fiber. More recently, the Department of Agriculture has made the provision of grains for gasohol an objective of commodity program policy.

At present, commodity programs are available for the major crops which account for over 80 percent of all sheet, rill and wind erosion in the United States(**3**).* The most important features of those programs with respect to conservation of land resources will be discussed here: price supports (nonrecourse loans), direct payments (target prices), and production controls (diversions, set-asides, and the allotment/**normal** crop acreage system).**

When they were initiated during the Great Depression, federal commodity and conservation programs were closely associated. In subsequent years they have evolved along separate lines. Conservation programs, based on a voluntary approach with technical assistance and federal cost-sharing, have developed to assist farmers with long-term conservation problems; commodity programs have become more oriented to helping farmers adjust rapidly to short-term market conditions with a minimum of government assistance (and cost).

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*Major crops will be defined as wheat, feed grains, soybeans and upland cotton.

**Target prices and set-asides do not apply to soybeans. Direct payments for disasters will not be analyzed.

There has been a general pressure to reduce federal expenditures for both programs over time, with the effect that the realization of long-term conservation goals has become more dependent on short-term market conditions and private farm income. Traditionally, farm conservation problems have been defined as the inadequate accounting of erosion (and other land degradation) costs in the short planning horizons most farm operators are believed to have(7). Compounding this omission is the incomplete knowledge of the long term costs and benefits of conservation(1).

Conservation problems resemble structure problems in the sense that the overall effects of commodity programs on them are not well understood, but are of considerable interest at the present time.

PRODUCTION CONTROLS

Cropland Set-Asides and Acreage Diversions

Production controls of various types have been used extensively in U.S. agriculture since the Second World War. Some of the programs involved long-term commitments from farmers to withdraw acreage, or even entire farms from production for as long as ten years. "While these longer term programs were primarily aimed at reducing crop production, a secondary objective was to promote permanent conversion from cro use to pasture or forest uses, especially in cases where the land was marginally suited for grain crop use." (11) Other programs required removal of a portion of a farm's acreage for one year at a time.

Under the Food and Agriculture Act of 1977 the secretary of agriculture may require farmers to set-aside a portion of their acreage in wheat, feed grains or upland cotton as a condition of eligibility for commodity program benefits. The secretary is also empowered to make payments to farmers who voluntarily divert cropland, whether or not set-asides have been declared. Both programs operate on a one-year basis, and acres set-aside or diverted must be planted in soil conserving crops. Set-asides for wheat and feed grains removed 19 million acres from production in 1978, and 12 million acres in 1979.

It is generally held that farmers remove their less productive lands first whenever a production control program is in effect. A 1969 study by the USDA (18) estimated that lands removed under production controls were only 80 to 90 percent as productive as lands retained in program crops. It is believed that the diverted lands have tended to be marginal, and more subject to erosion and other forms of physical degradation. As a result, even though the diversion of poorer lands has compromised the effectiveness of production control efforts--the so-called "slippage" phenomenon-- some conservation benefits have been realized. However, these benefits are short-term, and are only realized when production controls are in effect. (Diversions and set-asides were not used between 1974 and 1977, nor have they been declared for 1980.) Traditional production controls have thus been likened to "an extreme case of crop rotation" for least productive cropland (2).

Another contribution to slippage is the hypothesized tendency of farmers to intensify their use of inputs on that part of their land retained in production during production control periods. The effect on conservation here would depend on the type of intensification. For example, it is not known whether farmers have tended to fall plow to a greater extent in years when set-asides have been declared or anticipated. One study has suggested that acreage controls for wheat and corn modestly biased choices of inputs in North and South Dakota in the 1950s and 1960s. Fertilizer was substituted for other inputs in the case of wheat; while other inputs were substituted for fertilizer on North Dakota corn land. This study concluded that "although input controls (i.e., set-asides) may cause a reallocation of resources, the extent of that effect may be inconsequential and depends on the nature of production possiblities" for different farms in different regions(17).

It is also plausible that periodic set-asides, coming as they have in periods of low commodity prices, have had some influence on the increasing use of conservation tillage practices. A recent study of U.S. crop yields has noted that "because of increasing production costs (both fixed and variable)" farmers in recent years may have become "more concerned about net return per dollar investment than increased yield"(13). This may partially explain the incipient yield plateaux for certain U.S. crops observed since the mid-1970s. It may also suggest why farmers have adopted conservation tillage practices in recent years. Crosson (6) has argued that "the percentage of cropland in some form of conservation tillage has risen from a negligible amount in 1965 to 23 percent in 1979, almost solely in response to the economic advantages... relative to conventional tillage." The economic environment of the late 1970s may have signalled farmers that the era of set-asides had not yet passed, and they may have reallocated their resources toward cost-saving conservation tillage with the knowledge that these practices would also provide them a competitive advantage if they expanded their cropped acreage to more erosive soils in periods of high commodity prices(no production controls). The exact role set-asides may have played in this process is not known.

With respect to the enforcement of set-aside programs, a recent GAO report has noted that a small proportion of farms may take less than the required amount of land out of production when set-asides are in effect(16). Negative conservation effects could result from this form of non-compliance, depending on the use to which the non-diverted acres were put, and the quality and quantity of land involved.

As a final consideration, many agricultural economists predict that economic conditions in the years ahead will reduce, if not eliminate, the economic motives for set-asides and paid diversions. Potential conservation benefits of these production controls may thus be lost.

Acreage Allotments and Normal Crop Acreage

Beginning in the 1950s most U.S. farms growing major crops were assigned acreage allotments for specified (soil -depleting) crops and a "conserving base" for land that was fallow, idle, in cropland pasture, tame hays and forages, or in soil improvement crops. Both the allotments and the conserving base were determined by historical cropping patterns on individual farms. Commodity program payments were directly related to the size of allotments, and farmers tried to maintain allotments by planting the required portinn (usually 90 percent) to program crops. Likewise, farmers were required to maintain their conserving base to remain eligible for commodity programs.

Beginning in 1964, commodity programs have gradually been modified to counteract the fettering influence of allotments and bases on farm production decisions and cost-effective geographic shifts of crop production. A principal aim has been to give farmers greater freedom in deciding what they grow(14).

The Food and Agriculture Act of 1977 replaced acreage allotments for wheat, feed grains and upland cotton with a new concept, the normal crop acreage(NCA). Instead of being established for individual crops planted over a historical period, the NCAs are established for total acreage planted to program crops in the previous season. The conserving base concept has been eliminated.

Several conservationists have argued that the adoption of the NCA penalizes conservation-minded farmers. "The definition of "normal crop acres" in the new legislation does not include grass areas planted for conservation purposes. The conservation farmer who set aside such strips consequently suffered a reduction of his normal acreage relative to that of the improvident farmer. I am told there were even instances of farmers, after reading the new support legislation in advance, plowing under the acreage they had put to grass cover to increase their normal acreage"(10).

The agency responsible for administering commodity programs (the Agricultural Conservation and Stabilization Service) is aware of the potential conflict between NCAs and conservation objectives. However, the agency has not made an in-depth study of the situation, and therefore no quantitative measures of the effects of the NCA on conservation are currently available.

Generally speaking, changes in the allotment system have been in response to changes already underway in agriculture. The programs have been redesigned to rationalize, for example, certain geographic shifts in crop production induced by changing production efficiencies or technologies. Producers have not always welcomed the economic and programmatic changes. Cotton producers objected to the adoption of current plantings because it automatically included irrigated cotton regions of the west in the commodity program. To the extent that geographic shifts have resulted in the observed trend for crops to be planted on better quality land nationally(15), the modifications in the allotment system may be said to have complemented certain conservation goals (i.e., "plant the best and save the rest" at the national level). However, some land being cleared for cropland is coming from less intensive uses (such as forested bottomlands in the Delta region); and crop production on lands where irrigation is a necessity may not prove to be efficient in the long term if erosion, salinization or water supply problems develop or persist. It is not evident that these potentially negative effects on long-term land productivity have been explicitly considered in the design of production control policies. Indeed, the removal of NCA the requirement for certain 1981 crops illustrates the preeminence of food supply objectives in federal policy, for it is expected that unsound farming practices will be encouraged, specifically the conversion of grass lands to row crops. The rationale for lifting NCA requirements for 1981 is that farmers would have planted above their NCA anyway, in response to higher crop prices.

PRICE SUPPORTS AND DIRECT PAYMENTS

To support prices for the major crops the government offers farmers an opportunity to place their crops in storage as collateral for loans. Farmers may also recieve direct payments from the government for most major crops when market prices fall below specified "target prices" (deficiency payments), or when natural disasters strike (disaster payments). Farmers must comply with NCA and set-aside requirements to be eligible for these benefits. Together, price supports and direct payments protect farm income in years of low commodity prices. (Income effects of disaster payments are generally confined to localized areas in any given year.)

The most enduring hypothesis concerning farm income effects on conservation holds that higher incomes are associated with fewer erosion problems. It has been further hypothesized that farmers with higher incomes (1) generally farm better, less erosive lands (2)have more capital available for installing conservation measures, and (3) tend to adopt new technologies more quickly than do smaller, lower income farmers, including conservation technologies.

A recent analysis has shed some light on the relationship between net farm income and conservation at the national and regional levels(/2). Average rates of erosion on cultivated cropland did not vary significantly among income levels for all U.S. farms. But for full-owner-operated farms, which make up a quarter of all U.S. cropland, erosion rates on cultivated cropland tended to be lower as incomes rose.

For example, in the Corn Belt full-owner-operators with net farm incomes in the $0 - $2,999 range had mean erosion rates of 13.78 tons per acre annually on cultivated cropland. By comparison, those in the $3,000 - $19,999 range had 7.25 ton erosion rates; and full-owner-operators with net incomes between $20,000 - $49,999 had erosion rates of 4.38 tons per acre annually on their cultivated cropland. A similar trend was observed for the Northeast, Delta, Southern Plains and Mountain Regions, and for the nation as a whole. The study noted that "net farm income greater than $50,000 did not appear to result in significantly lower erosion rates," but because the acreage in this category was small, sampling errors may have been greater.

The study concluded that higher incomes were associated with lower erosion rates because the more affluent landowners had better land (40 percent of their cultivated cropland was erosion prone, compared to 59 percent for the lowest income group), and because they adopted more conservation practices. Landowners in the $50,000+ income category had minimum tillage or residue practices in use for 60 percent of their cultivated cropland, but landowners with net incomes of less than $3,000 had such conservation practices on only 47 percent of their cultivated cropland.

Commodity program benefits are concentrated with farmers whose annual cash sales of agricultural commodities exceed $40,000. Net farm incomes (including government payments) on these farms are generally above $25,000 per year. It could thus be argued that commodity benefits have contributed to the capacity of more affluent landowners to buy more land (4), and it is reasonable to assume they would also try to buy better lands. Government payments may also enable more affluent farmers to adopt more conservation measures more rapidly.

It should be noted, however, that government payments "are a smaller percentage of net receipts on large farms than on small farms"(9). Therefore government payments may be less important than cash receipts in promoting conservation investments. Nor do all conservation investments result in lower production costs. Those which do lower costs (as conservation tillage seems to do) may be adopted more readily by all farmers in periods when direct government payments form an important part of net farm income. On the other hand, expensive, structural conservation practices (such as terraces) may only be attractive in high price, high income periods when "farmers have both the capacity to invest and an incentive to avoid taxation by retaining earnings for modernization and expansion"--and, perhaps, for long-term productivity protection(9).*

The commodity programs, by reducing (socializing) economic risks and uncertainty for farmers, are generally said to promote specialization in farming. The income protection afforded farmers who place a greater proportion of their acreage in program crops may partially explain the more intensive use of cropland nationally, and the tendency of farms with larger sales to use cropland more intensively than farms with lower sales(8). More intensive use of cropland implies a decline in mixed crop-livestock operations in favor of less diverse, more specialized cash-grain operations. It also implies greater potential for resource degradation. Should the government role in risk reduction become less important in the future relative to reliance on export markets, the economic advantages of diversification might become more attractive to farmers, and some conservation benefits would be realized.

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*The Draft Program Report and Environmental Impact Statement for the Resource Conservation Act (RCA) notes (p. 5-41): "When market prices are higher, some farmers show a tendency to increase the installation and maintenance of those practices that do not interfere with production."

Without more precise information about the uses to which commodity program benefits are put, it is difficult to estimate their role in conservation relative to technological change and economic trends, or to predict how conservation would be affected by higher or lower program benefits on farms of various sizes in different parts of the country.

POLICY OPTIONS

Several types of proposals have been made to link commodity program benefits to conservation practices. The so-called "red ticket" approach would require farmers to adopt specific conservation practices on commodity program acreages as a condition for program eligibility. The "green ticket" and related "Conservation Incentives Program" (CIP) approaches would offer farmers marginally higher program benefits if they adopted specified conservation practices. This discussion will focus on the CIP, as articulated by Benbrook (1,2), for it has received much more favorable consideration in recent conservation policy deliberations(5).

The CIP is offered as a prototype for integrating conservation and commodity programs, and is intended to complement traditional conservation programs. "To qualify for benefits, CIP participants would be required to adhere to acceptable regional and crop-specific management practices...The basic guideline determining acceptibility of a CIP-approved managment system would be the capability to limit average annual per acre soil loss to or below the relevant soil loss tolerance limit." Participating farms would have as an addendum to their commodity program contracts a CIP plan specifying "an adequate soil conserving strategy consisting of simple, low-cost, and accessible BMPs (Best Management Practices) compatible with a farm's equipment and livestock feed needs." The practices would be recommended or required, as the farm's erosion potential warranted, but practices contributing to excessive erosion would be explicitly prohibited.

The incentives offered under the program would include: slightly higher target prices or loan rates; upward adjustment of disaster payments; relaxation of payment limitation; use of higher yield levels in payment formulas; and tax credits or deferrals.

The CIP could assist in supply control efforts under certain conditions, and could bring sound conservation practices to a much higher proportion of U.S. cropland.

One major drawback of the CIP is the probable lack of incentives to farmers in high price, high income periods. Many economists feel production control will be required with less frequency in the years ahead, and that market prices will remain relatively high. No direct payment incentives would be available to producers if market prices remained above target prices. In addition, unless payment limitations were lowered substantially from present levels, it is unlikely that "relaxation" of them would attract many farmers, since few producers exceed the limitation at the present time. Although they have not been analyzed, administrative costs might be high for the CIP. Finally, farmers of less productive (lower capability class) soils where erosion problems are most likely to occur would have to adopt the most rigorous conservation practices to qualify for the CIP. Without additional cost-sharing assistance, incentives for these farmers might not be adequate to bring them into the program, and critical problem areas might be missed.

Research And Impact Assessment For Commodity Program Effects

One of the striking features of commodity program/conservation interaction is the relative dearth of information and analysis on the national environmental impacts of commodity program activities. A precedent for an environmental impact statement for federal conservation programs was established in Section 6 of the Soil and Water Resources Conservation Act of 1977(RCA). Initiation of a similar assessment for commodity programs could marshall information from states and federal agencies on the effects commodity programs have had on a variety of environmental conditions. This might be the first step in identifying critical problems created by the programs in specific areas, as well as identifying politically acceptable solutions which might or might not involve changes in the commodity programs themselves.

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Background Paper No. 5

PROBLEMS OF COST-SHARING PROGRAMS FOR LONG-TERM CONSERVATION:

THE EXAMPLE OF THE AGRICULTURAL CONSERVATION PROGRAM

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Background Paper No. 5

Problems of Cost-Sharing Programs For Long-Term Conservation: The Example of the Agricultural Conservation Program

As the total demand, and particularly the export demand, for U.S. food and fiber increases in the decades ahead, American farmers will respond by shifting more land to cash grain crop production, and by using presently cropped land more intensively. The magnitude of future demand, as well as the effects it is likely to have on agricultural resources, are the subjects of considerable debate. But it is generally agreed that more exhaustive use of soil and water will occur in the next thirty years.[1]

Federal programs to conserve soil and water resources were designed, and, for the most part, have operated during an era of "surpluses" in American agriculture, when land was periodically removed from production to bolster farm prices. With the prospect of greater pressure on these resources, a number of Federal organizations have begun to examine the effectiveness of traditional conservation programs. These programs provide education, technical assistance, and financial assistance in the form of cost-sharing and loans for conservation practices, to farmers who voluntarily undertake to conserve their resources. Yet it is not clear that the programs are adequate to protect the long term productivity of agricultural land. Some critics have even argued that the programs have performed poorly over much of their history.[2]

Probably the most controversial component of the "voluntary approach" to conservation is cost-sharing--the reimbursement of farmers for part of the cost of installing certain conservation practices on their lands. Cost-sharing has been an integral component of Federal conservation policy for over forty years. At present, eight Federal programs administered by the Department of Agriculture offer such cost-sharing to landowners.[3]

Both the general public and farmers seem to support the idea and the actual performance of cost-sharing programs.[4] Indeed, in a 1979 Harris poll, only 12 percent of the public thought it would be fair to taxpayers and to farmers to impose "mandatory programs which require the farmer exclusively to pay for the cost of conservation." About 35 percent of the respondents in the poll favored "loans and other financial help to farmers who volunteered to protect their water and soil". Twenty-seven percent of the respondents favored loans and financial aid for participants in a mandatory conservation program.[5]

With such broad public and political support, cost-sharing approaches to conservation are certain to remain important to Federal conservation policy. However, several studies conducted in recent years have pointed to major weaknesses in current cost-sharing programs. In some cases these weaknesses have been used to justify proposals for elimination or reduced budgets for specific programs, for it has appeared that the social investment (the Federal portion of the cost-share) has resulted primarily in short-term economic benefits to farmers, rather than long term social benefits (reduced erosion or water consumption).

Of all the Federal conservation cost-sharing programs, the Agricultural Conservation Program (ACP) is the most controversial. Established in 1936, the ACP is the country's largest cost-sharing program. Roughly $8 billion in Federal funds have been distributed to farmers through the program, which is available in every country in the nation. (The total annual program budget has been about $200 million in recent years, with about 300,000 farms participating annually.)

The program is administered at the national level by USDA's Agricultural Conservation and Stabilization Service (ASCS), but most of the important administrative decisions are made by State committees and, to an even greater extent, by farmer-elected county committees. The authority of the county committees includes "identifying conservation problems, setting priorities, selecting appropriate cost-share practices, setting levels of cost-sharing, approving applications, entering into contractual obligations, and making payments for completed conservation work".[6]

Problems With ACP Cost-Sharing

Two general and interrelated problems have repeatedly surfaced in examinations of the ACP: the need for balance among State, local, and national levels to insure overall program effectiveness; and the tendency for ACP monies to be used for production-oriented practices instead of practices yielding long term conservation benefits.

A partial examination of the ACP by the U.S. General Accounting Office (GAO) in 1976-77 found that "In recent years, less than half the program funds have been used for measures that are primarily oriented toward conserving the Nation's topsoil. Most of the money has gone toward measures that, although eligible for funding, are primarily production-oriented--thus financially benefitting farmers--or that result in minimal soil conservation."[7]

The GAO evaluation team noted that "county committees generally assigned priorities to the practices for which Federal cost-sharing funds were to be spent but these priorities were frequently not followed. In some cases, practices designated by county committees as high priority or critically needed to control erosion received only a small percentage of the available funds, whereas other practices considered to be production oriented or of a temporary nature were approved by the committees and heavily funded on the basis of popular demand." (Emphasis added.)

A much more thorough evaluation of the ACP was conducted by ASCS in 1977.[6] This study added a new twist to criticism of the ACP, for it showed that many of the practices specifically intended to control erosion were placed on land that did not have serious sheet and rill erosion problems. (Sheet erosion is the washing of a fairly uniform layer of soil from a slope, and rill erosion is the formation of small channels from which soil particles are eroded. These two types of water caused erosion account for most of the country's total erosion.)

Table 1 indicates the distribution of nine erosion control practices installed with ACP assistance according to pre-practice erosion rate and excess erosion. Two salient points can be made about the data. First, it is clear that a very large proportion (52 percent) of the erosion control practices installed under ACP nationally have gone on land where sheet and rill erosion is below 5 tons per acre per year--the average soil loss tolerance for cropland soils as established by USDA's Soil Conservation Service (SCS). (This soil loss tolerance is often called the "T" value.)

However, it is important to note that the impact of ACP practices on reducing wind erosion was not a part of the first phase of this evaluation. Thus, some of the practices which appear in Table 1 to have been applied to land with minimal erosion problems may in fact have been applied to land where wind erosion is severe. Until the impacts of wind erosion have been incorporated in the evaluation, it will be impossible to say exactly how many ACP erosion control practices have gone on essentially non-problem lands. What can be said is that the proportion is probably quite large.

The second important implication of Table 1 is that ACP practices have not very effectively reached lands where sheet and rill erosion are known to be severe. Note that approximately 82 percent of the "excess" (greater than 5 tons per acre annually) sheet and rill erosion occurs at rates of 14 or more tons per acre per year (last column). Yet only about 18 percent of the ACP erosion control practices went on land eroding at these high rates (second from last column).

TABLE 1

Comparison of percentage distributions: Acreage by erosion rate; assisted by practices by pre-practice erosion rate and excess erosion, 171 sample counties, Agricultural Conservation Program, 1975-78

Erosion rate in tons per acre annually	Percent* of acreage	Percent of practices 1/	Percent of excess erosion*	Cumulative* percent of acreage	Cumulative 1/ percent of practices	Cumulative* percent of excess erosion
0 - 1	59.2	16.6	—	59.2	16.6	--
1 - 2	12.7	14.2	—	71.9	30.8	—
2 - 3	7.0	9.0	—	78.9	39.8	—
3 - 4	4.6	7.0	—	83.5	46.8	—
4 - 5	3.2	5.6	—	86.7	52.4	—
5 - 6	2.2	4.4	0.6	88.9	56.8	0.6
6 - 7	1.7	4.6	1.6	90.6	61.4	2.2
7 - 8	1.3	4.2	1.9	91.9	65.6	4.1
8 - 9	1.0	3.0	2.0	92.9	68.6	6.1
9 - 10	.8	3.3	2.0	93.7	71.9	8.1
10 - 11	.6	2.7	2.1	94.3	74.6	10.2
11 - 12	.5	2.1	2.0	94.8	76.7	12.2
12 - 13	.5	2.9	2.0	95.3	79.6	14.2
13 - 14	.4	1.6	1.9	95.7	81.2	16.1
14 - 15	.3	1.3	1.8	96.0	82.5	17.9
15 - 20	1.1	5.9	8.4	97.1	88.4	26.3
20 - 25	.7	3.3	6.8	97.8	91.7	33.1
25 - 30	.4	1.7	5.6	98.2	93.4	38.7
30 - 50	.9	3.5	19.0	99.1	96.9	57.7
50 - 75	.4	1.5	13.7	99.5	98.4	71.4
75 - 100	.2	.7	9.3	99.7	99.1	80.7
100 +	.3	.9	19.3	100.0	100.0	100.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

*Source: National Resource Inventory, USDA-SCS.

1/ Data is cumulative for nine ACP erosion control practice studied. Listed on table 6.

SOURCE: National Summary Evaluation of the Agricultural Conservation Program, Phase I. USDA, ASCS. 1981

One consequence of this observed distribution of ACP practices among different erosion rates has been reduced cost-effectiveness of Federal (and complementary private) investment. Table 2 indicates that a lot more conservation could be purchased with existing Federal monies by shifting funds to erosion-prone lands.

The data in Table 2 show the cost per ton of erosion reduction for nine erosion control practices (and all practices cumulatively) at successive erosion intervals. Most of the erosion control practices are concentrated in erosion intervals where per ton reducation costs are very high. According to the USDA analysis: "The cost per ton of erosion reduction declined from $14.87 per ton when practices were applied to lands eroding at rates of 5 tons per acre per year or less to an average of $2.69 per ton for land eroding at rates ranging from 5-to 10 tons per acre annually." From Table 1 it can be noted that over 42 percent of the country's "excess" sheet and rill erosion occurs on land with 50 or more tons of erosion annually. "The average cost per ton of erosion reduction declined by almost 80 percent as the pre-practice erosion rate increased from 5 to 10 tons per acre annually to 10 to 15 tons per acre per year... At the extreme, the average cost per ton of erosion reduction is only one-half of 1 percent of what it is when the same practices are applied to lands eroding at less than 1 ton per acre annually."

The manner in which the per ton costs were calculated requires that they be viewed with some caution. (For example, all installation costs were charged against erosion control benefits, though other benefits were likely realized. And again, the amount of reduction in wind erosion that may have been achieved in some cases has not yet been measured.) Nonetheless, the relative magnitude of the costs shows that the ACP would be much more cost-effective if more of

TABLE 2

AVERAGE COST PER TON OF EROSION REDUCTION BY
PRE-PRACTICE EROSION RATE
171 SAMPLE COUNTIES
AGRICULTURAL CONSERVATION PROGRAM
1975-1978

Average annual soil loss before treatment (tons per acre)	Type of Practice									
	Establishing permanent vegetative cover	Improving permanent vegetative cover	Stripcropping	Terrace	Diversions	Interim cover	Conservation tillage	Competitive shrub control	Vegetative cover on critical areas	Average for all practices
	----Average Cost Per Ton of Erosion Reduction in Dollars----									
0 - 1	57.48	69.80	7.57	9.48	28.98	65.52	63.47	11.20	68.39	45.40
1 - 1.99	15.97	9.01	7.10	6.91	18.52	61.39	4.98	3.16	5.77	14.23
2 - 2.99	6.36	4.91	6.28	3.43	11.24	31.53	2.35	1.58	--	5.85
3 - 3.99	4.32	3.04	2.15	3.14	12.18	29.13	1.76	1.64	.29	4.19
4 - 4.99	3.81	2.76	.92	4.13	9.91	18.43	1.50	.83	4.38	4.70
5 - 5.99	2.93	2.05	1.61	3.60	3.84	15.30	.90	.78	4.37	3.10
6 - 6.99	1.89	1.72	1.14	2.68	2.98	15.19	.98	.51	2.96	3.46
7 - 7.99	1.81	1.38	.52	2.57	4.67	9.49	.53	.61	.38	2.33
8 - 8.99	1.60	1.21	.88	2.66	1.52	7.69	.53	.46	.44	2.40
9 - 9.99	1.31	1.07	1.07	2.08	3.79	7.21	.61	.13	.89	2.16
10 - 10.99	1.20	1.03	1.43	1.68	2.16	6.77	.39	.33	.84	2.16
11 - 11.99	1.00	.84	--	1.95	.49	5.77	.39	.33	.59	1.57
12 - 12.99	.85	.66	.30	1.43	.57	5.95	.83	.66	.21	1.54
13 - 13.99	.89	.64	1.07	1.12	.99	3.99	.61	1.06	.49	.94
14 - 14.99	.80	.57	--	1.21	.54	3.90	.21	.30	.42	1.12
15 - 19.99	.59	.54	.69	.99	.61	3.94	.32	.19	.27	.84
20 - 24.99	.45	.45	.06	.87	.44	3.07	.29	.32	.21	.54
25 - 29.99	.38	.36	--	.76	.63	2.38	--	.03	.26	.48
30 - 49.99	.26	.24	.02	.44	.29	1.81	.08	.51	.25	.39
50 - 74.99	.17	.14	--	.15	.14	2.21	.13	--	.46	.24
75 - 99.99	.14	.13	--	.03	.08	2.19	.04	--	.15	.22
over 100	.10	.06	.01	--	.07	1.36	--	.01	.16	.21

SOURCE: National Summary Evaluation of the Agricultural Conservation Program, Phase I. USDA, ASCS. 1981

LAYOUT SHEET - VARIOUS REDUCTIONS

the practices were placed on the more erosive lands. The evaluation states:

> "Effectively targeting erosion control funds according to the potential for erosion reduction could more than triple the amount of soil saved through the program. Achieving these improvements hinges on the willingness of farmers with severe erosion problems to participate in the program."

Implications of ACP Evaluation for Federal Cost-Sharing Policy

One possible approach to getting these farmers into the ACP is to give them preference in ACP cost-sharing, and to raise both the limit on overall Federal spending per participant (now at $3,500 per year) and the Federal share of practice costs. Farmers lacking severe erosion problems could be discouraged from participating in the program altogether. These approaches were suggested in an earlier evalution of the Great Plains Conservation Program (GPCP) administered by SCS, but they remain untried.[8]

Additional soil savings could be realized "by concentrating assistance on the most efficient practices, such as stripcropping, conservation tillage, and competitive shrub control." The cost-effectiveness of these and other erosion control practices can be compared for successive erosion intervals in Table 2.

Other policy implications of the ACP evaluation, which may be applicable to other Federal cost-sharing programs, are as follows:

1) An increase in Federal funding alone will not necessarily produce a proportionate increase in long-term resource conservation.

2) More quantitative information is needed on erosion problems at the county committee level. The information would most likely be supplied

by SCS field personnel, and therefore a larger budget for SCS technical assistance in this area may be required. One option would be to increase from the current five percent level the proportion of the ACP appropriation which goes to SCS for technical assistance.

3) To insure that information on the specific resource problems of each applicatnt are used as criteria for awarding ACP cost-sharing (for either soil or water conservation), more explicit Federal guidelines may be required.

4) Depending on subsequent cost studies and local conditions, an effort should be made to eliminate cost-sharing for the less cost-effective resource conservation practices, much as has been done to eliminate production-oriented practices from the ACP in recent years. This process will also probably require a larger Federal role.

5) The Great Plains Conservation Program (GPCP) evaluation indicated that program would operate more effectively if funds were reallocated among states to accord with their relative conservation problems. Such a reallocation would probably enhance the Agricultural Conservation Program as well as the Resource Conservation Act process has identified both conservation problems and objectives at the state level, and these could be used to adjust the current allocation of ACP funds to target more money to priority problems and regions.

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Background Paper No. 6

IMPACTS OF RANGELAND TECHNOLOGIES AND OF GRAZING ON PRODUCTIVITY OF RIPARIAN ENVIRONMENTS IN UNITED STATES RANGELANDS

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Background Paper No. 6

IMPACTS OF RANGELAND TECHNOLOGIES AND OF GRAZING ON PRODUCTIVITY OF RIPARIAN ENVIRONMENTS IN UNITED STATES RANGELANDS

Oliver B. Cope[1]

ABSTRACT

Aquatic and riparian environments subject to grazing in the rangelands of the Western States are described in terms of quantity, quality, economics, social factors, cultural resources, and technology changes and their effects on these environments. Impacts of grazing on these habitats are discussed, including erosion, siltation, streambank stability, stream-morphology changes, soils, vegetation, hydrology, fish, and animals wastes. Variables that influence the intensity and magnitude of grazing effects are addressed, including terrain, geology, climate, management schemes, type of grazing animal, insects and rodents, and cultural modifications.

Technologies for improving the riparian zone are treated, including reversibility of conditions, technologies that aggravate or alleviate the problems, and new technologies. Management strategies for restoration, enhancement, and maintenance are discussed. The ways grazing damages aquatic and streamside areas are described, and the utility of management strategies for restoration is considered. Our understanding of the nature and extent of degradation is explored, and research and research needs for improvement of these habitats are discussed. Priorities for research are methods for inventories and evaluations of range conditions, alternative grazing systems to benefit riparian/stream

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zones, supplemental methods for improving streams and streamside areas, and sound monitoring methods.

Effects of government policies on productivity in these environments are described, and policy changes to improve conditions on these rangelands are suggested. Priority policy changes are better agency compliance with laws and regulations relating to the management of riparian/stream habitats, funding at levels to make possible agency compliance with laws and regulations, additional cooperative efforts among agencies to solve stream and streamside problems (including research), and training of personnel involved in range-related work.

INTRODUCTION

There is a national debate going on concerning the relationships between grazing and fish/wildlife well-being on various rangelands in the United States. The specific sphere that has attracted the most interest in this discussion is the interaction between grazing and the riparian/stream environment in the West.

It is a basic ecological principle that everything in an environment is related to everything else in that environment. This becomes especially apparent in the riparian/stream area, for this is a highly complex, heavily used, and easily disturbed habitat. The understanding and management of streams and their borders become particuularly challenging in light of the many uses and user objectives identified with the zone--conservation of range and pasture resources, production of food and fiber, improvement of fish and wildlife habitats, increasing opportunities for outdoor recreation, concern for endangered species, protection and improvement of water quality, and assuring that energy resources are used in an environmentally acceptable and cost-effective manner.

The complicated task of using these resources to the advantage of all parties has been addressed in several forums in the past few years, and all the involved disciplines have participated. From these communications we have a mass of results and ideas on problems and solutions regarding joint management of livestock, fish, wildlife, plant life, soils, and water. This report consolidates and organizes the important expressed facts, objectives, and policies which focus on the grazing/riparian zone/stream problem.

AQUATIC AND RIPARIAN ENVIRONMENTS SUBJECT TO GRAZING IN RANGELANDS OF THE 11 WESTERN STATES

Quantity

To set the stage for a characterization of the streams and streamside zones in grazing areas, we can examine some statistics which reveal the magnitude of the involved areas. Of the total land areas in the U.S., 63 percent (1.2 billion acres) have been or are being grazed by livestock (1). The 11 Western States have 622 million grazable acres, of which 504 million were being grazed in 1970. Approximately half of these 504 million acres were on private land, and the other half were on public lands administered by agencies such as the Bureau of Land Management (BLM), the Forest Service (FS), the Fish and Wildlife Service (FWS), the National Park Service, the Bureau of Indian Affairs, and the military. More recent surveys (2) show that 75 percent of the western land under federal control is being grazed. BLM administers 174 million acres, of which 170 million are classed as rangeland (3); on this land are 19,000 miles of fisheries streams and 523,000 acres of riparian areas bordering the streams (4). Estimates today are that 138 million acres of FS lands support grazing.

Quality

Rangelands, as defined by the Forest Service, include native and natural grasslands and pastures, including streams and their riparian environments, as well as forest communities suitable for grazing by livestock. Grazing is considered to be the harvest of grasses, forbs, shrubs, and trees by domestic and wild hooved mammals.

The focus in this report is on the relationships among grazing, grazing lands, and the aquatic zone (stream)/riparian zone (moist and vegetated streamside). Riparian zones have vegetation that requires more moisture than that of the upland areas (5), and have great variety in their size and complexity because of the variety of combinations of water source, topography, soils, type of stream bottom, quality of the water, altitude, and the plant community. In the Western States, riparian zones of the moist Northwest contrast with those of the arid Southwest, and those in the high mountains are different than those of the plains. Despite this multiplicity of characteristics, the riparian areas in rangelands in the West all have some common traits: they are well-defined habitats within the drier surrounding areas; they represent only a small part of the overall area; they are usually more productive of plants and animals than the surrounding area; and they are more diverse than the remainder of the rangelands.

Wildlife (invertebrates, fish, reptiles, amphibians, birds, mammals) use riparian and aquatic zones much more than any other habitat, so the zones are the most important wildlife habitats in rangelands. Riparian zones, because of their highly productive forage and the availability of drinking water, are also used by cattle more than are other areas. The riparian is also valuable for recreation, locations for roads, as sources of rock and gravel, and as sources of water for many of man's uses.

Riparian zones are not only valuable--they are also extremely sensitive and subject to disturbance. The features that make these areas so valuable are also the features that contribute to their fragility. The distinctness and maturity of the vegetation, and the edge effects and diversity in the best zones, make these associations vulnerable to management activities in the zones or on nearby rangelands. Changes in vegetation create changes in the animals that live, eat, and reproduce there, and in the quality of the water and the aquatic life in the stream. Changes in vegetation in riparian zones can be brought about by road construction in the zone, construction of campgrounds, improper grazing practices, and other human activities, and they interact with water quality, soil compaction, soil erosion, and streambank breakdown.

There is considerable evidence that streamsides in the 11 Western States have been damaged on a large scale. Historically, our past use of rangelands has been inefficient (6). The earliest good assessment of the condition of western rangelands was in 1935, when 58 percent was classed as poor or bad, 26 percent was fair, and 16 percent was good or excellent. By 1966, poor or bad ranges had improved to 33 percent, fair range had declined to 49 percent, and good or excellent range stood at 18 percent. In 1972, federal rangeland was rated at 32 percent poor or bad, 50 percent fair, and 18 percent good or excellent. Although the methods for collecting this information have been criticized, it is clear that the nation's rangelands are in better condition than they were 50 years ago. A little more than two-thirds of FS rangelands were considered to be in satisfactory condition in 1976 (7). Despite this improvement in range quality, however, authorities agree they are not producing near their potential (6,8).

BLM in 1975 determined that the range condition on BLM lands had the following percentage ratings: excellent--2; good--15; fair--50; poor--28; bad--5. It is predicted that, at the current management level, in the year 2000 the ratings would be: excellent--4; good--18; fair--43; poor--29; bad--6.

A problem with the acceptance of evidence for gains in nationwide range condition is that the analyses of ranges have focused mainly on the drier, terrestrial sites, with little attention given to riparian areas (9). Some workers believe that riparian habitats in forested areas are as deteriorated now as they have ever been during European man's history in the U.S. Examples of recent measurements of condition of riparian zones are seen in Environmental Statements covering western areas. On the Uncompahgre Basin in Colorado in 1977, it was reported that 28 percent of the riparian was in a good state, 38 percent was fair, and 19 percent was in poor condition (10). On the Grand Junction, Colorado resources area in 1979, there were 845 riparian acres in good condition, 1,475 in fair condition, 2,276 in poor condition (11). These areas may not represent the entire West, but the data suggest that streamsides are not as healthy as they could be.

Economics

In recent years there has been increased attention to the economics of interactions among rangeland, range degradation, range improvement, livestock, and wildlife. Utilization of models and computers has enabled resource managers to understand better the costs and benefits from various uses of the range and to predict economic results. However, most of the economics research has been done in relation to non-riparian areas.

Monetary values of vegetation, fish, and wildlife in streams and streamside zones are difficult to measure, but dollar values of fish populations have sometimes been estimated with reference to sport and commercial fishermen and nonconsumptive users. An example is seen on the Salmon River in Idaho, where 1974 net annual values for salmon and trout were estimated at 10.8 million dollars (12). An analysis has been made (13) to conceptualize values of rangeland use for ranchers, consumers, and hunters, and to recognize economic ramifications of improved management on fish and wildlife. The researchers concluded that if stream corridor management were to be implemented for overgrazed, degraded riparian zones, economic gains would be considerable. In addition to benefits from sportfishing, there would be benefits to game and nongame wildlife, reductions in erosion, improvements in water quality, etc.

Environmental Statements issued to cover operations and management by federal resource agencies contain detailed descriptions of economic factors in individual areas (10). These factors (range livestock-related income, construction-related income, employment, and public finance and tax base) are addressed in terms of existing conditions and in terms of conditions to prevail after recommended management changes. Again, however, these assessments do not show dollar values associated with the streamside zones. Improvement or deterioration of fishing, camping, sightseeing and hiking opportunities, water quality, and livestock use of streamsides and streams are discussed; they reveal changes in the economy, but not in monetary terms attributable to streamsides.

Social Factors

Social factors, closely allied to economic factors, can be affected by range-management practices. Some of these are short-term effects that involve the individual livestock operator and others, and some are long-run consequences important to the community, individuals, and the Nation (3). Affected are community and individual incomes and lifestyles, public attitudes and values, impacts on employment, landownership patterns, implications for subdivision and land speculation, public health, and recreation opportunities. Improving the productivity of rangelands will provide an improved future for individuals and communities.

One assessment of social status and range management has been made in Idaho (14), where some objectives and desires are support of the family farm, dispersed populations with a high regard for the stability of government, dispersed production units that are openly competitive in the market system, and a highly efficient system for the production of food and fiber. The best rangeland management will contribute to the fulfillment of these aims, and riparian areas, as the most critical and valuable portions of the rangelands, must be considered as prime ingredients of any management scheme that will enhance these social factors.

Cultural Resources

Cultural resources are non-renewable, fragile remains of human activity (structures, artifacts, works of art, architecture, etc.) on public lands. There is documentation of damage to historical campsites, rockshelters, towns, and homesteads through erosion and trampling by livestock (15). Since most of these structures are located near springs, streams, and rivers, good management of the riparian zones probably could have helped avoid this damage; reduction in the rate of soil erosion and livestock activity would cause a slower rate of change to these resources.

Technology

Many technologies have been practiced on western rangelands in the past 100 years, some for the benefit of livestock, some for timber production, some to help farming, some for recreation, some for road construction, some to enhance fish habitat in streams, some in the name of wildlife management, some for sewage and waste disposal, and some for mining activities. All of these have caused changes in the riparian zones--some have had beneficial effects, but they are overshadowed by those that have been detrimental. The harmful effects have generally resulted in vegetation deterioration, loss of nesting, feeding, and protective cover for birds and mammals, streambank deterioration, shallower and wider streams, higher stream-water temperatures, sediment-covered stream bottoms, loss of food input from terrestrial insects, loss of fish spawning beds, and loss of fish.

There is widespread opinion that the greatest of these impacts has come from livestock grazing (16). Grazing technology and strategy before 1934 (when the Taylor Grazing Act was passed) consisted mainly of unrestricted cattle and sheep grazing on public lands (8); much of the land presently managed by BLM was depleted by overgrazing during this time. Riparian areas were part of these overgrazed ranges. After 1935, technologies in grazing practice introduced on public lands were: elimination of sheep "tramp herds", assignment of allotments on which grazing herds can be monitored, general reduction of livestock grazing on FS and BLM lands, and regulation of early spring grazing. These practices resulted in better conditions on riparian and other rangelands (8).

One problem of application of technologies stems from the single-land-use objectives practiced by the various management groups with interest in rangelands. Laws such as the National Environmental Policy Act of 1969 gave authority for comprehensive and systematic planning to insure that all factors are taken into consideration on the national resource lands (17). This multi-use planning system provides for use of technologies to help several users, rather than grazing alone. Allotment management plans are designed to improve rangeland vegetation by manipulating grazing animals. This technology has made use of several grazing systems to better distribute livestock on the range and provide improved plant growth and vigor (18). Complementing the allotment system, technologies involving range improvements such as fertilization, seeding, undesirable plant and animal control, mechanical soil treatments, water spreading and drainage, prescribed burning, and timber thinning were put into effect after 1935 to improve range forage. Water developments, fences, trails, and similar improvements have permitted more effective grazing management on riparian and other rangelands. Other technologies such as kind of livestock, seasons of use, and grazing intensity or stocking rates have been studied and put to use, but must be further studied for a better understanding of their utility. The development and use of these technologies have resulted in improvements in many rang lands since 1935, but improvements in riparian zones have lagged behind those in other parts of the range. Questionnaires distributed in Idaho (19) and reported in 1979 revealed that forestry organizations, industry, the American Forage and Grassland Council, rancher/farmers, research groups, the Society for Range Management, soil conservationists, and wildlife and conservation groups felt more knowledge and technology are needed for rangelands in multi-purpose management.

IMPACTS OF GRAZING ON AQUATIC/RIPARIAN ENVIRONMENTS

Erosion

Grazing by cattle, sheep, deer and elk can lead to erosion near and in the streamside zone. When overgrazing takes place, the vegetation is removed or damaged and heavy rains are not absorbed by the soil and run overland to cause erosion (20). Not only does overgrazing cause this, but trampling by livestock contributes to the breakdown of the vegetation (21). Soil depletion is not merely a steady loss--it accelerates with each new loss, resulting in less absorptive capacity, organic matter, and plant growth to protect the soil from the next rain (22). This combined effect leads from bad to worse, with formation of gullies and surfacing of subsoil materials not capable of supporting revegetation. As the riparian surface becomes barer, the way is open for even more transport of sediments because of removal of litter or living vegetation which otherwise would trap soil materials and form miniature terraces.

Both domestic and wild hooved animals can cause erosion on streamsides through trampling and vegetation destruction. Cattle are considered to be the greater hazard, however, because deer and elk rarely congregate in the same large numbers over long periods as do cattle, especially during the often-critical periods of spring and summer. Cattle grazing, if properly controlled, can be useful by maintaining the vegetation in a preferred state of succession by stimulating the regrowth of grazed plant species.

Siltation

Runoff of sediment-laden water from streamsides into the aquatic zone causes siltation in streams and rivers. Sediment is by far our nation's largest single water pollutant, and about half of all sediment originates on agricultural lands (23). Sediments clog stream channels, destroy aquatic habitats, create turbidity, degrade water needed for consumption or other uses, and carry other pollutants such as plant nutrients, pesticides, toxic metals, and bacteria and perhaps viruses. Sediment has a twofold effect on the environment--it depletes the riparian from which it comes, and it pollutes the stream in which it is deposited.

Large grazing animals cause siltation in streams when they damage vegetation and trample the streambanks; this leads to soil erosion and the transport of soil materials into the stream.

Streambank Stability

Streambanks along smaller streams furnish the habitat edge needed for high fish population densities (24). Fish often adapt their survival to this habitat edge because streambanks give cover, control water velocities, and supply terrestrial foods that enter the stream. The state of the streambank often controls the depth and velocity of the water the fish live in. Stable streambanks are an important part of the habitat quality needed by fish in small streams.

Streambanks also provide habitat for birds, mammals, and reptiles which need the protection, food, space, nesting and breeding sites, and other factors afforded by stable, vegetated riparian zones. Edge effects and ecological diversity on streambanks, as compared to adjacent upland areas, enhance the value of riparian zones to these forms of wildlife.

Breakdown of streambanks is associated with breakdown of vegetation on the banks and other parts of the riparian area, erosion, trampling by cattle and other large animals, and other factors discussed in this section. These effects are often reciprocal (erosion damages plants, and damaged plants enhance erosion), and, unless checked, become progressively more severe. Naturally occurring, stable, well-vegetated streambanks help maintain stream-channel integrity (24). They provide cover for fish and reduce exposure of the water surface to solar radiation (cooler water). Equally important, they reduce sediment originating from streambanks, thereby protecting the quality of the entire aquatic environment. Stable banks also help prevent the lowering of the water table, as sometimes results from intense grazing.

An objective of riparian zone management is to have streambanks with 80 percent or more of their lineal distance in a stable condition for optimum trout production (25). Control of grazing is a most useful technique for achieving this goal.

Stream Profile Changes/Stream Morphology

The profiles, cross-sections, and size-and-shape characteristics of streambeds are vital to the welfare of the animals and plants living in the stream. The best trout streams have favorable proportions of pools, runs, and riffles. In general, narrow and deep channels promote better trout density than do wide, shallow channels. Undercut banks, debris, rocks, aquatic vegetation, and overhanging brush provide valuable cover for fish. These conditions, together with favorable physical and chemical conditions on the stream bottom, comprise an aquatic ecosystem that should support healthy populations of fish, invertebrates (fish food), and aquatic vegetation.

It has been demonstrated that cattle grazing in Montana contributed to the degradation of streams by changing stream morphology and reducing fish populations (26). The vegetation in the riparian zones is reduced, erosion takes place, overhanging banks collapse, sediment enters the stream, pools on the stream bottom fill with silt, water quality declines, fish spawning beds become clogged with silt, fish eggs and fry and invertebrates are deprived of oxygen through the action of fine sediments in the stream gravel, and fish productivity declines. Fishery interests desire that no more than 15 percent of the streambed substrate be covered by inorganic sediment (25).

With 50 percent of the substrate covered, trout production is reduced to approximately 17 percent of the potential.

Soils

Grazing by large animals in the riparian zone can have serious effects on soils, both on the streamside and in the stream channel. There are many kinds of soil in the western states--soils in the moist coastal regions, alternately barren and vegetated soils of the arid and semi-arid regions, soils of the montane regions, and soils of the prairies. Soils vary in morphology, texture, organic matter, density, crust hardness, and other features. The nature of soils is important in their support of vegetation and in their reaction to disturbance.

Soils in riparian zones are more valuable than those of surrounding lands because of their better productivity, which is attributable to more water, higher organic matter, more plant nutrients, and better infiltration rates. The soils in streamside zones are self-sustaining physical/chemical/biological associations that are continuously forming new materials under the influences of climate, living organisms, parent rocks, topography, and time. Thus, they should become more valuable as time passes. The loss or degradation of these soils, therefore, is more serious than soil losses in nearby areas.

Cattle activities that affect soils are overgrazing, trampling, and deposition of wastes. Overgrazing damages plant life and leads to erosion and sediment transport, resulting in soil loss. Sometimes the topsoil is completely lost through scouring, and subsoil or deeper materials become exposed. These deeper materials do not support vegetation, so the riparian has lost much of its value. Trampling by cattle causes compaction of the soil, causing a reduction in water infiltration, and makes successful reproduction difficult for many species of plants. The lowered ability of the soil to absorb water encourages erosion, sedimentation, and bank sloughing.

Deposition of cattle or wildlife feces may help fertilize soils and stimulate plant growth in the riparian area, but these same nutrients may be damaging when they reach the stream. Feces and carcasses may also introduce coliform bacteria and other pathogens to the soils and to the water (21), posing potential health problems for recreationists, animals, and other water users.

Vegetation

Plant life in the streamside zone has relationships with all other elements of the environment. Plants and water, plants and climate, plants and streams, plants and fish, plants and terrestrial animals--all these are vital relationships that characterize the zone. Vegetation is the principal component addressed in this report, and is the central focus in the complex issue involving grazing and the riparian zone.

Vegetation in streamside areas takes many forms and is composed of many combinations of species. Native riparian cover consists of grasses, forbs, shrubs, and trees, in different proportions from place to place. The different cover types have connections to other components of the environment. The grasses and forbs furnish protection, nesting cover, brood cover, feeding cover, resting cover, escape cover, and feed for upland birds; dens, feed, and cover for small mammals and reptiles; feed and resting cover for big game and cattle; and shade and fish food over streams. Shrubs provide feeding and nesting cover for birds and mammals, and shade and insects for streams. Trees give nesting and feeding cover for raptors and other large birds, feed and shade for large and small mammals, and shade and insects for streams.

Relationships between plants and erosion, sedimentation, soils, streambank stability, etc. have been discussed above. When livestock graze in the riparian zone, trampling and vegetation loss can result, followed by erosion, sedimentation, etc., as slated earlier.

For wildlife production in the streamside area, it is recommended that the zone should provide at least 80 percent of the potential production of grasses/forbs, shrubs, and trees (in sites that would naturally be dominated by trees) (25).

Hydrology

Water movement from precipitation to soil to stream in well-vegetated riparian zones is characterized by high rates of infiltration in the soil, slow release of water to the stream, and low erosion and sediment-transport rates. Vegetation tends to promote soil stability and reduce runoff and sediment losses (27). Grazing affects rangelands primarily by altering the protective vegetation, thereby altering erosion and sediment movement. However, trampling by grazers also compacts the soil and causes water to move across the soil instead of infiltrating. The runoff of water is thus increased by both these processes, and substantial amounts of sediment can be carried into the stream. In the stream, the sediment may settle in pools, changing the stream profile and rendering the stream less useful for fish. The sediment may also cover fish spawning beds and the gravels that support invertebrates; this reduces the movement of water through the gravels and deprives the bottom-dwelling organisms of oxygen.

An effect on hydrology is also brought about when erosion and loss of vegetation cause collapse of streambanks. This results in a changed channel cross-section--the channel becomes wider and shallower and the hydrology of streamflow is modified. Moreover, as mentioned above, water tables may be lowered.

Fish

There is considerable documentation to indicate that grazing on riparian areas can be detrimental to fish populations. The above discussions on effects of grazing on stream habitats have shown that grazing has added pollutional siltation to streams, affecting invertebrate population densities and fish spawning. Grazing has also been responsible for rises in water temperatures in cold-water streams, and decreases in numbers of fish-food insects that fall into the water from overhanging trees and shrubs. Stream-morphology changes have damaged fish habitat--changes that arise from siltation due to damage on streambanks.

Five independent studies (28) in western states showed a 184-percent average increase in trout production in areas of controlled or light cattle grazing as compared with heavily grazed areas of the same streams. It was estimated that trout production in streams being heavily grazed could be increased about 200 percent if management decisions were made to optimize habitat conditions for trout. In Idaho, fencing part of the aquatic and riparian habitat of a stream resulted in dramatic improvement in stream habitat within the fenced area and in larger, more numerous rainbow and brook trout in the fenced portion compared to the unfenced part (29). In Nebraska's Otter Creek, fencing the upper stream to exclude livestock caused rapid habitat recovery in the stream, increased rainbow trout smolt production 2 to 4-fold, and changed the fish species composition, almost eliminating white suckers and creek chubs and greatly reducing brown trout populations (30).

Animal Wastes

Excretion materials from livestock and wild animals can create pollution in soils, vegetation, and water in rangelands (31). Various pollutants have variable effects on rangeland streams. Nitrogen and phosphorus are essential nutrients for plant growth. Aquatic vegetation of the free-floating type, such as algae, depends on dissolved nitrogen and phosphorus compounds for a nutrient supply. When periodic flushes of these nutrients in feces are injected into rangeland streams, dense, rapidly multiplying algal blooms may occur. Often, such growths of algae are undesirable to water users and may interfere with other forms of aquatic life. The enrichment of a water body in this way can be an adverse result of excessive nutrient loading (21).

Animal wastes may cause depletion of oxygen in the stream water; this can be of great importance to aquatic ecosystems and can be affected by range-management actions. Land characteristics, wildlife populations, hydrology, and climatic conditions all tend to interact to influence and compound the effects of grazing on non-point source loading and pollutant transport and effects.

Fecal coliform bacteria in streams do not necessarily prove that they came from domestic livestock, for wildlife can also be a source. Coliform organisms are used as an indication of bacterial water pollution; they may come from soil, water, vegetation, and feces. The effects of grazing on soils and infiltration rates (discussed above) can increase sediment and attendant chemical and nutrient pollutants, and microorganism transport.

VARIABLES THAT INFLUENCE INTENSITY AND MAGNITUDE OF GRAZING IMPACTS

Terrain

The natural terrain in which a riparian zone is located can have considerable influence on the soil/water/vegetation complex in the zone and on its ability to withstand disturbances. Topography, aspect, slopes, soil type, stream-bottom type, elevation, and plant communities are variables that can affect the impacts discussed in the previous section. The combined effects of geology, climate, geomorphology, soil, vegetation, and water runoff often result in unstable stream conditions in the natural state (18). When land uses place additional stress on aquatic habitats, damage usually results.

Topography and stream gradient affect the movement of water and animal access to the riparian zone. Streams originating in the high mountains normally have steep gradients, falling 25 feet or more per minute. Here we see high-velocity water, coarse bedrock material, and a narrow channel that passes through a steep-walled bedrock gorge (28). Riparian zones are narrow and poorly vegetated, so water moving toward the stream is not slowed by plant life and soils. Protection of the streamsides from grazing is usually not a problem here, for the riparian is not productive and is not used by cattle (the cattle cannot even reach some areas because of the steepness and narrowness of the streamside).

The gradients and water velocities decrease at medium elevations. Here, the streams often have sand-gravel bottoms, floodplains, wider and more productive riparian zones, and are extensively used for grazing and other agricultural purposes. At these elevations, the riparian is vulnerable to grazing damage through vegetation degradation, soil compaction, and sediment movement.

In the lower, pastoral zones, the terrain changes again, with a more gentle topography, finer bedload material, and stable banks beside a deep, meandering channel. Streambanks are often steep and tree-lined, and water velocity is much reduced. Here we see an even more productive streamside area, but one which is even more susceptible to damage from grazing because agricultural use is heavier than at higher elevations.

Geology

Geological factors that influence the effect of grazing on the riparian are physical and chemical in nature. The geologic processes by which streams were formed and the geomorphic types (alluvial, valley train, dissected mountain slope) determine some characteristics of the streams. The gradients, the elevations, the dissolved and suspended solids in the water, stream width, and stream depth evolving from these geologic beginnings help control the density and composition of fish populations (32).

The chemical and physical nature of soils derive from the nature of the rocks from which they were formed. Soil physics and chemistry in the riparian area is important to the nature of the vegetation they can support, in their water-holding abilities, and in their resistance to erosion and sediment movement. Thus, the geologic background of the stream and riparian zone is intimately related to the plant cover, the productivity of the stream, and the adjustments they make to grazing.

Climate

Climate and weather factors that are important in the welfare of the streamside zone are temperature, winds, and moisture. Precipitation, length of growing season, temperatures of air, soil, and water, and winds and their fluctuations all affect the condition of the vegetation and the soils on streamsides and on surrounding sites.

Precipitation and drought are usually not as serious a problem to riparian vegetation as in the surrounding areas. Growth in plants is related to a balance among rainfall, runoff, soil moisture, and evapotranspiration (33). In riparian zones, by definition, soil moisture and plant production are higher than in nearby areas. The advantage gained by riparian vegetation (over non-riparian vegetation) during dry periods makes the riparian areas even more attractive to grazers, and intensifies the problem of vegetation damage due to grazing.

During periods, and in localities, of high air temperatures, the shade afforded by trees and shrubs overhanging small streams becomes relatively more valuable as a temperature-reducing force for stream water than during times, and in places, of moderate air temperatures. The problem of controlling grazing to preserve shrub and tree vegetation thus becomes more critical than at other times and places.

Use/Management Schemes

The imposition of land-use and land-management schemes can have numerous influences on the riparian, in terms of effects of livestock grazing. Some of the effects are favorable to the maintenance or improvement of the quality of the soil, water, vegetation, wildlife, fish, and livestock resources, and some are damaging.

Fencing to exclude livestock will benefit most riparian areas by preventing overgrazing and trampling, but the design and placement of the fence can allow or prevent large-wildlife movement into and out of the streamside, depending on fence height, height of the bottom wire, and smoothness of the bottom wire (34). Fencing standards should specify minimum height so deer can go over and smooth bottom wire so antelope can pass under.

The many grazing systems that have been used have had various effects on the streamsides, depending upon the kind of grazing, when the grazing was done, and the intensity of grazing (35). Heavy, continuous cattle grazing is undesirable for most wildlife on the streamsides and fish in the streams. Light-to-moderate cattle grazing is often beneficial and does not adversely affect many species. In some forest areas, light cattle grazing is used to help maintain herbaceous openings. Grazing seasons can be designed to protect the riparian, either yearlong or at critical times of the year.

Allocation of grazing permits for livestock is often based on unrealistic range surveys and their measurements of range carrying-capacity (36). Too often, range carrying-capacities are overestimated, resulting in abnormally heavy livestock use. When this happens near stream areas, pressure on the riparian is increased, and the impacts on soil, vegetation, water, and wildlife (and, in the long term, livestock) are intensified. Another problem with determination of carrying-capacities has been that allocation has often been made for cattle to use all of the carrying capacity, leaving no allocation for wildlife. Sometimes, allocations are made for deer, elk, or other major species, but small game and nongame are ignored.

Management strategies that focus on animal species management instead of ecosystem management can affect the influence of grazing on streamsides. Both wildlife interests and livestock interests emphasize the importance of animal values, but ecosystem management, in which attempts are made to keep as many wildlife niches as full as possible to build stability and diversity on rangelands, would often benefit the riparian through enhancement of water, vegetation, and soils (36).

Vegetation manipulation for land and range management can have a bearing upon grazing on streamsides. Between 1963 and 1967, over 2 million acres of land in the contiguous United States were subjected to vegetation modification. This was done primarily to convert various types to grass, mostly for domestic livestock. We do not know if riparian areas profited from this manipulation, because many observers have reported that when manipulation is done away from the riparian, livestock continue to use the riparian before they use more distant ranges. As a result, overgrazing and habitat damage continue. Conversion of sagebrush and other shrubs, and forbs, to grasses is detrimental to some wildlife species (deer, antelope, sage grouse) which need the shrubs and forbs.

Some range management in the past has amounted to control of brush or woody vegetation. To manage for both livestock and deer, management (rather than control) of vegetation has proven to be a better concept (37). In Texas, preservation of this woody vegetation has left escarpments, stream courses, strips, blocks, and other patterns of woody cover to provide diversity for the needs of deer. The objective is to control enough brush to increase livestock forage production, but leave enough browse cover to take care of the wildlife. The riparian, of course, benefits from this practice because of decreased pressure from livestock grazing.

Type of Grazing Animal

The type of grazing animal can make a difference in effects on the riparian zone. Elk prefer grasses, deer prefer forbs and shrubs, cattle prefer grasses (but readily utilize forbs, shrubs, and other plant life on overgrazed ranges), domestic sheep like all understory plants except old, established browse plants, wild horses and burros eat the plants that cattle (and some wildlife) like, and goats eat more shrubs, forbs, and litter than grasses. These diet preferences can cause competition for feed between livestock and wildlife, competition which becomes more intense where vegetation is sparse due to drought, overgrazing, etc. This competition often places the riparian in a vulnerable position when the surrounding areas cannot satisfy the dietary needs of the animals.

In addition to competition for food, wildlife and livestock are sometimes incompatable for other reasons. While deer and cattle can graze side-by-side, elk move out when cattle move in (38).

Some kinds of animals have a greater tendency to overgraze than do others, because of feeding behavior and food preferences.

Insects and Rodents

Insects on plants in rangelands (grasshoppers, aphids, plant bugs) can consume considerable amounts of vegetation. In a forest ecosystem, normal insect grazing may consume 5-30 percent of the foliage (39). Studies in Oregon showed that insects were more abundant on grazed range areas outside an enclosure than on ungrazed areas inside, probably because of better vigor and quality in the plants in the grazed area.

Other insects, and mites, have an important role in recycling dead organic matter, so are important in soil formation and nutrient conversion. Many insects are important in range revegetation and rehabilitation through pollination, destruction of seed, and gall formation. Thus, insects help increase forage, on the one hand, and retard it on the other. Use of insect-resistant strains of grasses during range revegetation can reduce some detrimental effects of insect infestation; this practice inside and outside of the riparian zone can change the impacts of grazing by redistributing grazing pressure.

Perhaps the greatest impact in the riparian from insect management could come from insecticide applications, on and off the area. Sprays and granular applications adjacent to the streamside can drift or wash onto the streamside and produce mortality among birds, mammals, reptiles, soil organisms, and terrestrial invertebrates. Insecticides applied directly on the streamside can cause morbidity and mortality to the same animals. Insecticides dispensed in both areas can drift or wash into the stream and kill fish and aquatic insects. Organophosphate insecticides are particularly toxic to birds and mammals, and chlorinated hydrocarbons are especially damaging to fish, reptiles, and amphibians.

It has been established that rodents have been partially responsible for die-offs of browse plants and a scarcity of browse seedlings on the range (40). So serious is this problem in some habitats that resource managers have engaged in poisoning operations to control rodent populations. This kind of program poses problems for the wildlife community in terms of the loss of one component of the environment (plants) versus loss of another part (small mammals and their predators).

Management hazard implications appear with the possibility of mortality to non-target animals. Poisoned bait placed for control of mice, ground squirrels, or pocket gophers may be washed or transported by small animals into the riparian and/or into the stream. Poisons such as Compound 1080 and zinc phosphide have been found to do little damage to birds (41), but death among small mammals is not uncommon.

Cultural Modification/Improvement

Archeological and historical resources pose special problems on the riparian because of their unique nature and high value. Archeological sites are damaged by surface disturbance, causing loss or damage to horizontal or vertical cultural deposits, loss of paleoecological data, and disturbance or loss of natural sedimentary deposition (causing destruction or mixing of artifacts and destroying evidence of human use and occupation at a site) (10). Management problems and procedures commonly seen in management of the riparian and which could cause this kind of disturbance are livestock trampling and rubbing, spring development, water projects (pipelines, troughs, wells, catchments, reservoirs), trail construction, cattle guards, fence construction and use, chainings, seeding, and contour furrowing. In general, livestock grazing does not cause significant adverse impacts on archeological sites except where soil stability is poor and secondary geologic processes can take place as a result of overgrazing.

Sociocultural groups and values have instrumental, territorial, sentimental, and symbolic orientations to resources (42). The relationships of these groups to lands, ranges, forests, streams, wildlife, and recreation is important in planning for land-use and management, and could affect the strategy and techniques of protection of the riparian.

TECHNOLOGIES FOR IMPROVING THE RIPARIAN ZONE

Reversibility of Conditions

Most of the problems and complicating variables discussed above can be reversed, given sufficient time, money, technology, legislation, and public and private support. There are, of course, some situations that cannot easily be reversed--geologic structure, topography, climate, basic soil type, some soil erosion that exposes sterile rocks over large areas, some hydrology, archeological features, and perhaps some sociocultural patterns.

Many seriously impacted riparian areas can be restored to acceptable states only after painstaking efforts, long periods of time, and great expense. Severe erosion, heavy siltation, unstable streambanks, stream profiles and cross-sections, soil quality, vegetation quality, and fish, bird, and mammal populations can be corrected, developed, or replaced with various techniques now available.

Moderately damaged riparian zones and their streams can often be improved rather quickly and at little expense by removing the conditions that caused the damage. Mild erosion, vegetation damage, sedimentation, stream shape, soil quality, water quality, and fauna can often heal in a few years by the simple act of removing the cause of the damage (29,30,43).

There are all degrees of damage, many levels of desired improvement for different uses of the environment, and many kinds of technology available to bring about restoration. Decisions must be made for each situation by the public, resource managers, and administrators as to what costs (money, time, effort) are to be paid for what benefits.

Technologies that Aggravate or Alleviate the Problems

Management technologies used for streams and streamsides can help alleviate problems. Stream-improvement procedures (placement of log and rock deflectors, construction of check dams, placement of riprap or tree limbs on banks, placement of boulders in the streambed, planting on streambanks, changing the course of streams) improve stream profiles, remove sediment, decrease erosion on banks, create improved pool:riffle ratios, and alter water velocities. However, if problems causing the original degradation are not solved, the improvements are usually temporary. These changes interact to counteract some of the adverse effects of grazing by improving riparian soil and vegetation conditions. Seeding and transplanting vegetation on and near the riparian, and even some habitat-modification procedures (soil-fertilization and moderate mechanical treatments on and near the streamside) have caused improvements in riparian-zone quality.

General range-management practices principally designed to increase the abundance of forage for livestock have variable effects on the streamsides because livestock can continue to overgraze and damage streamside zones. The fencing-off of streamsides is the common management tool advocated by some individuals for protecting riparian areas--the more effective in separating livestock from the streamsides, the better the response from the riparian. Numerous examples can be cited to demonstrate the benefits to vegetation, soils, fish populations, and water quality derived from elimination of grazing (24, 29, 30, 43, 44), whether done for protection or for recovery and later use. However, fencing is not a panacea for healing damaged riparian zones at all sites; expenses are high for constructing and maintaining the fences, and if vegetation outside the fenced area cannot support original livestock numbers the numbers must be reduced or additional forage must be furnished through vegetation manipulation practices, which, in themselves, are expensive. If fences are built but not maintained, or if they are not properly designed, the benefits to the riparian are reduced accordingly.

Grazing systems may be helpful or harmful to riparian zones, depending on the system used. Some people believe systems featuring no grazing are the best for streams and streambanks; yearlong and season-long grazing systems are the most harmful. Poor-to-fair effects arise from deferred, rotation, and deferred-rotation plans, and variable impacts are caused by rest-rotation and short-duration/high intensity systems (45). However, it is possible that some of these systems would be acceptable if site-specific management plans are designed.

Development of seeps, springs, and water troughs for livestock is a technology that helps the riparian, especially if provision is made for wildlife use of the facilities.

Water diversions for cattle use can be beneficial for the streamsides and for wildlife, but this procedure should be followed only when the diversion does not seriously deplete the flow of water in the stream from which diversion is made.

Herding, a technology for controlling the density of livestock in an area, can be helpful to the riparian, as long as the timing and physical conformation are favorable. This system requires coordination among ranchers to insure that some pastures are rested, when necessary, to benefit streamsides.

The development of food and mineral stations, and shade, for livestock in areas distant from the riparian can be very helpful to the soils, vegetation, water, wildlife, and fish habitat of the streamside and the stream.

Some measures to improve the state of plant life away from streamsides--revegetation (seeding and transplanting) and range fertilization--are usually welcome to people interested in protecting the riparian, for these steps can be helpful if grazing pressure is decreased in the riparian. Other technologies for changing the vegetation on the range (burning, chaining, railing) can have deleterious effects on the riparian through soil disturbance that encourages erosion and sediment movement.

Insect and rodent-control operations and herbicide treatments can be helpful to the riparian if they are very carefully done, but there is often the possibility that the dispensed toxic materials can drift or wash onto the streamside and into the stream and kill animals or plants.

Wild horses and burros can harm the riparian zone. This problem is unusual because present management cannot control numbers of animals (17). The range will continue to be subjected to reduction in productivity due to abuse unless acceptable and practical management controls become effective. Damage to the open range from these animals will place growing pressure on the plant life of streamsides.

New Technologies

Past and present technologies for solving grazing/riparian/stream problems have focused mainly on treating symptoms rather than causes. Most of these operations have been trial-and-error attempts, and when positive results have been achieved the gains have been temporary. The livestock industry has continued to concentrate on methods of producing forage for livestock, and has developed no new technology that has enhanced stream/streamside areas. The few new procedures proposed or tried by aquatic/riparian interests relate to treating symptoms of damage to the riparian, rather than solving basic problems attributed to overgrazing.

One reason agencies have been reluctant to develop new technologies has been resistance from the livestock industry, at all levels, to the development and implementation of new technology because of their belief that attention to management of riparian/stream areas is an ulterior motive for the eventual removal of livestock from the ranges (46).

In the area of mechanical devices for operations in the environment, there has been some progress in treating symptoms; various improvements in design of tillage, seeding, and planting implements have been made, and their use might improve the efficiency of these operations and reduce erosion and sedimentation (47). A device for controlling pocket gophers, the burrow-builder, constructs and automatically baits artificial runways (48), and may reduce hazards from poison bait. Equipment for removing silt from the gravels of stream bottoms has been developed recently, and, within the limits of stream-bottom morphology and total area to be cleaned, may be a valuable tool for counteracting effects of sediment in streams (49). It has also been proposed that the use of electric fences (45) may afford protection to riparian areas where it is needed for 2-5 years after improved management practices are applied.

Technologies involving management strategies to solve problems associated with overgrazing are beginning to emerge, and may have utility. One pertains to a grazing system--the Santa Rita Grazing System. This is a 1-herd, 3-pasture, 3-year rotation geared to the habits of perennial grasses on semidesert ranges, and is especially beneficial where animals congregate, as around water (50).

New concepts for managing riparian zones are beginning to appear. A holistic approach would couple the riparian with other parts of river corridors, considering the streamsides as essential and integral parts of the whole stream corridor instead of being managed on its own (51). Other innovators advocate the recognition of the riparian as a separate management unit.

New, important technologies are beginning to operate in the realm of quantitatively evaluating and forecasting habitat quality (52, 53, 54) and the impacts of grazing, although few have been thoroughly tested.

Another factor that is beginning to make a difference in the riparian/grazing issue is the increase of organized activity of public users. Recognizing that there are serious problems on the riparian, that the National Environmental Policy Act of 1969 requires the preparation of grazing impact statements in order to implement improved management practices, and that statement preparation is behind schedule, environmental groups are being heard, with some effect, in many arenas (55).

MANAGEMENT STRATEGIES FOR RESTORATION, ENHANCEMENT, AND MAINTENANCE OF AQUATIC AND RIPARIAN ENVIRONMENTS

Management strategies for the streamside should have a basic structure, including a commitment to act, definition of realistic management objectives for the habitat, design of a site-specific management plan (including technologies), and monitoring of habitat responses (hypothesis, design, statistical testing, and making conclusions). If the management meets the objectives, continue the management; if not, change the objectives of the management plan.

In light of this kind of approach, very few management strategies have been put into effect on the riparian rangelands. Many procedures, technologies, and techniques have been used for restoration, enhancement, and maintenance of aquatic and streamside environments, but their use has usually not been part of planned strategies.

Some general management steps that assist in all phases of habitat husbandry are the training of personnel; the formation of management guidelines; the dissemination of information to resource personnel, administrators, and the public; and planning. These are essential in management, and must be done effectively to insure the proper application of specific field procedures.

Strategies that protect these zones from damage are appropriate grazing systems; coordinated management; appropriate livestock, wildlife, and vegetation allocations; site-specific concepts; monitoring changes in the environment; and use of buffer zones in connection with insecticide and herbicide applications. These procedures have great value in the restoration of the riparian and the streams, but their application is also very useful in maintenance and enhancement of these areas.

Among the procedures directly applied to streams and streamsides, stream-improvement structures; range improvement and habitat improvement on the riparian and nearby range; multiple-use; inventories and monitoring of the habitats; site-specific actions; and grazing systems that insure light use and stimulation of vegetation growth are valuable tools. They all, singly or in combination, aid in restoration, maintenance, and enhancement of riparian and aquatic zones, with changes in specific techniques as the habitats move from phase to phase. For example, willows might be planted on streambanks to reduce erosion (a restoration step), and grasses and forbs might later be seeded or planted farther from the stream (maintenance and/or enhancement steps). During both these steps, fences might be placed to exclude livestock/wild animals from the revegetating sites.

There are differences among the strategies in their applicability in assuring continued diversity, viability, and productivity on riparian and aquatic environments. It is difficult, however, to rank each management scheme in order of importance to diversity, viability, and productivity because of the multiplicity of interactions among soils, vegetation, water, and the other features of these habitats. This is one reason for the advocacy of site-specific approaches to management of riparian/ stream areas (5). Some approaches, however, are known to be helpful in all areas degraded by grazing. The prevention of grazing in the riparian, either by fencing or by appropriate grazing systems, is probably the most useful single management strategy for restoration and maintenance of the riparian and aquatic zones and in assuring the return of diverse, viable, and productive vegetation. When other measures are added to this--stream improvements and bank stabilization through reduced erosion and revegetation--the dividends are compounded, and both ecosystems gain in productivity. The other management procedures discussed above contribute to the welfare of these zones in different, unmeasured ways in different situations, but they all contribute.

Improvements in stream and riparian habitat after cessation of grazing have been measured in several places. Mahogany Creek in Nevada (43), Summit Creek in Idaho (29), Otter Creek in Nebraska (30), Camp Creek in Oregon (56), and other streams have demonstrated significant improvements in riparian vegetation, stream shade, terrestrial wildlife, fish populations, and bank conditions after grazing was stopped. On some of these, other management stategies were also put into effect, but non-grazing was the chief cause of improvement.

GRAZING DAMAGE AND GRAZING MANAGEMENT SYSTEMS

Grazing influences the productivity of the stream/riparian environments by adversely affecting fish populations and their habitats; changing the composition of riparian plant life; changing stream geomorphology by altering streambanks, increasing channel sedimentation, and changing channel dimensions; increasing sediment transport and water temperatures; not maintaining or restoring, without special protection for the stream and banks, healthy and productive riparian/stream zones; and failing to fully use the potential of the stream to produce a fishery resource and forage for livestock and wildlife (57).

Some grazing times and grazing intensities are better for the riparian than are others. The most productive riparian and aquatic habitats occur in the absence of livestock grazing. Yearlong grazing may be more detrimental to aquatic habitats than some rotation systems (57). Season-long grazing concentrates livestock at favored locations, especially along streamsides, inadequately uses the herbage available, and overuses the more desirable forage plants (18). Rest-rotation often requires more livestock movement, increasing the trailing potential in the riparian. There is no published evidence that implementation of rest-rotation grazing for badly degraded streams in arid areas has resulted in markedly improved conditions for fish (57). Heavy grazing is more damaging than light or moderate grazing (light/moderate grazing may be beneficial in some places by increasing growth of some plants).

Winter grazing may be beneficial in areas where streambanks are most susceptible to damage by livestock. Here, delayed grazing until lands are frozen may minimize damage. This can be used where snow accumulation is low, so cattle and sheep can continue to graze and ranchers have easy access for supplemental feeding (45).

Spring or fall grazing, during times of cool days and cold nights, feature movement of livestock out of riparian zones and greater use of steep slopes that get little use during hot summer months. Damage to streambanks by cattle trampling may be more evident during spring grazing if soil moisture is high.

Summer is the time of most cattle grazing in the West. At this time shade, cool and moist ground, available water, succulent forage, and more level topography make the riparian zone the most attractive to livestock. This, then, is the most critical season for grazing effects on the environment.

Ranges, including the riparian, need periodic rests from grazing at critical stages of plant growth (spring and summer) (3). Periods of nonuse by livestock grazing allow natural processes to progressively improve soil-water infiltration rates to predisturbance levels (21). Somewhat a function of season and clearly a function of rest length, deferment of use might be used as a technique for hydrologic condition restoration and to achieve forage-production and maintenance goals.

Actions which minimize adverse changes in stormflow and snowmelt runoff processes will simultaneously minimize adverse water-quality impacts (21).

Depleted streamside environments can sometimes be restored by selection of site-specific grazing management systems. The most obvious improvements have happened where grazing has been eliminated, as on Otter Creek in Nebraska (30), Summit Creek in Idaho (29), and Mahogany Creek in Nevada (43). In these situations, badly damaged stream and riparian habitats showed dramatic improvements in only 1-2 years--improvements in water quality, bank stability, stream shape, vegetation and shade on banks, and quality of fish populations. On Camp Creek in Oregon (56), an exclosure eliminated all grazing. After 4 years, vegetation and banks had improved, so cattle were allowed to graze within the protected area in mid-August; this practice has been followed since 1968, with no apparent change in fish habitat and populations.

Not all riparian/stream zones respond as quickly as these examples; some response takes 10 years (28). The speed and extent of recovery depend on the extent of deterioration, the climate and natural vegetation, the potential for improvement, the amount of restoration desired, the physiology of the plants and their response to grazing, and other factors.

In instituting a grazing management scheme for preserving, reestablishing, or enhancing vegetation on streamsides, one must consider the kind of vegetation involved. Systems such as continuous rest-rotation or deferred rotation in various forms have generally been developed considering only the production and maintenance of forage plants--primarily grasses and forbs for livestock (5). It is likely that the application of such systems to maintain woody streamside vegetation and streambank integrity will need consideration of the physiology of trees and shrubs as much as that of forage plants. There is no technically defensible evidence that rest-rotation grazing, without special protective measures for the stream and streambanks, will restore or maintain a healthy, productive riparian/aquatic zone.

Experts have stated (59) they doubt that the present grazing strategies are capable of solving the problems in the aquatic environment caused by grazing. Some grazing systems, by themselves, can restore some areas. In other places, grazing schemes need help from other management procedures (stream improvement, plantings, etc.). The key is site-specificity--each degraded area must be viewed as a separate case, evaluations made, objectives defined, and grazing systems and other approaches put into effect.

UNDERSTANDING RIPARIAN ZONE DEGRADATION

Although some effort has been made by resource managers and researchers in the past to try to reach an understanding of the nature and extent of aquatic and riparian environmental damage, we do not yet have the knowledge we need. Few advances have been made in documenting the condition of the riparian range on public lands and quantifying the extent of damage (17); this has been done by only a few agencies and has not always been done in detail. Extensive and intensive inventories of streams and streamsides, using technically valid, standardized techniques, are sorely needed in terms of quality of each kind of habitat and in terms of acceptability for livestock, fish, wildlife, and humans.

The Data Base

The nature of the degradation on range areas is known, over wide areas, only in general ways. The BLM has assembled information of variable accuracy and depth on acres and miles in need of improved management. Some states have collected data on percent of stream surface shaded, streambank stability, streambed sedimentation, grass/forb cover, shrub cover, and tree cover, but these new programs are generally in the method-development stage and have covered only a small part of their streams and streamsides. The preparation of Environmental Statements for selected areas is improving our knowledge of the specific nature of riparian deterioration on these areas. The data base that documents changes in these environments is not as extensive as resource managers need. The inventories of condition and management potentials on streams and streamsides, in general, are incomplete and lack sufficient details, except in a few places.

Research

Research on many problems attending the grazing/stream/streamside complex has been done on a modest scale in the past few years, but is entirely inadequate at the present time. Aquatic biologists, range researchers, foresters, water-quality specialists, hydrologists, economists, and other specialists all recognize the inadequate state of our knowledge, and the need for more research.

Needed research on technologies must address kinds of grazing systems to benefit riparian/stream habitats and the interactions of the systems with all components of these habitats, procedures for predicting effects of management, and techniques for monitoring mitigation and improvement (60); methods of inventorying these habitats, ways of detecting natural variations in streamside vegetation, stream-channel conditions, and fish standing crops and community structure, and quantification of artificial changes and describing the potential of damaged habitat and fish and wildlife communities to respond to improved management (59); techniques for allocating riparian range vegetation, managing livestock to benefit riparian/stream areas; water management and improving water quality through management; and techniques to accelerate the recovery of damaged habitat--techniques which do not necessarily require fencing to exclude livestock.

Research is also needed on better planning procedures; methods of cooperation among users, government agencies, and the public; socio-economic concerns; and selling the importance of the riparian areas (3, 18).

Priority in research and technology development should be given to methods of inventorying and evaluating stream/riparian range conditions, alternative grazing systems to benefit streamside/stream areas, supplemental methods for improving and maintaining stream and riparian habitats, and technically defensible monitoring methods.

GOVERNMENT POLICIES AND PROGRAMS

Federal resource agencies operate under the authority and guidance of many laws and executive orders for using and protecting the environment and its resources. Of those laws that give authority for management and improvement of public lands, the Taylor Grazing Act of 1934, the Wild Free-Roaming Horse and Burro Act of 1971, the Federal Land Policy Management Act of 1976, and the Public Rangelands Improvement Act of 1978 are especially important to grazing management. Among laws that provide a national policy framework within which rangeland management must function are the Sikes Act of 1960, the Endangered Species Act, the Federal Water Pollution Control Act, the National Soil Conservation Act and the Soil Conservation and Domestic Allotment Act, the National Environmental Policy Act (NEPA), and the scoping requirement in the Council of Environmental Quality Guidelines of 1978. Some laws establishing policy for special uses, resources, and animals are the Fish and Wildlife Coordination Act, the Fisheries Conservation and Management Act, the Migratory Bird Conservation Act, the Clean Water Act, and the Bald Eagle Protection Act. Some executive orders delineating policy direction affecting range management are E.O. 11593 for protection of cultural resources, E.O. 11988 for protection of floodplains, and E.O. 11990 for protection of wetlands.

In addition to legislation to help public agencies manage rangelands, several interagency agreements are in place. A 5-way agreement among the BLM, Soil Conservation Service, FS, Geological Survey, and FWS for program coordination, another between the BLM and FWS, and other agreements operate for interchange and recommendations on range management.

Influences of these laws, orders, and agreements on habitat quality and productivity in aquatic and streamside habitats have been variable. The Taylor Grazing Act of 1934 is credited with slowing the deterioration in condition class for BLM and FS ranges (8). The BLM (16) estimated in 1975 that 22.7 percent of 264 miles of stream were improving, 64.8 percent were static, and 12.5 percent were declining; big game, small game, and nongame habitat are in poorer condition than the streams, and projections are for declines in wildlife habitat condition and wildlife populations under current management levels.

The other laws and agreements governing range management on public lands have potential to help improve riparian areas and other rangelands, but implementation has been slow and results have not been significant for riparian habitat. NEPA, by requiring environmental statements, should eventually result in restoration of a considerable amount of stream and riparian habitat. However, the BLM has been slow in devising updated range-management plans and preparing its grazing impact statements; this has been partly due to a huge workload (144 management units), inadequate funding, lack of personnel, and attitudes which in the past have predominantly emphasized managing rangelands solely for the production of livestock forage. The BLM has become more responsive in the past few years; however, it does not have a policy which requires special management and attention to riparian/stream areas.

The Endangered Species Act, requiring special protection for certain fish, other animals, plants, and habitats, is certain to afford potential relief for some streams and riparian areas when strategic plans for each species and habitat are put into full effect. Thus far, we have no measurement of improved habitat quality or productivity on any significant scale as a result of this Act.

The Federal Land Policy and Management Act of 1976, when its effects are felt, could potentially help in planning and operations on the range by giving fish, wildlife, and recreation equal status with livestock grazing; BLM-administered lands were formerly managed with livestock production as the primary goal. The quality of the riparian could improve when the provisions of the Act are fully implemented.

Executive Orders 11988 and 11990 provide for protection and management of floodplains and wetlands; we do not yet see the results of these promising tools.

The scoping requirement in the Council of Environmental Quality Guidelines requires agencies planning to prepare environmental statements to involve other agencies and concerned parties in planning. Effective in 1979, this requirement has not yet influenced an overall improvement in habitat quality or productivity in the riparian.

Policy Changes

Changes in policies and programs can be expected to change the quality of habit and the productivity of these environments in a positive way. The implementation of the laws and agreements discussed above (several of which are relatively new) can undoubtedly bring improvements if there is compliance on the part of the management agencies. Another factor which has detracted from the desired interagency cooperation on solving stream/riparian range problems has been the reluctance of some agencies to become involved. For example, the FWS has not had a formal programmatic approach for contributing to overall improved management of fish and wildlife habitat on ranges, nor have they systematically participated in land-management activities with the FS and BLM. These recent legal developments can now function to help agencies such as the FWS to participate actively in solving rangeland problems as they affect fish and wildlife if the agencies identify range problems as major impacts on fish and wildlife resources.

On the favorable side, the FS began an assessment program in the Rocky Mountain Region a few years ago--a program to assess the significant riparian and aquatic habitats and plan corrective action on at least two of them on each National Forest in the Region (61). The FS is working with the Demonstration Allotment Committee of the Colorado Cattlemen's Association to develop and demonstrate livestock management which can improve riparian areas while maintaining or improving the livestock operation. This new program shows great promise.

To bring about improvement and increased productivity of these zones, policy changes should be sought from several levels of influence. Congress should attempt to fund the resource agencies at adequate levels so the laws and regulations described above can operate. More personnel are needed by the BLM, FS, FWS, and other agencies to do the planning, make the surveys, write the reports and recommendations, and administer the rangeland programs mandated by NEPA and other laws. We should seek a policy that emphasizes more research and technology development on several facets of the grazing/riparian question, making more use of talent and facilities already in the agencies. Emphasis should be increased on training of agency personnel who are and will be involved in range-related work so they can develop a sensitivity to riparian/stream habitat requirements to cause them to deal more effectively with problem solving.

Some agencies should improve their organizations so range problems can be better addressed--identify problems and scope program options and budget requirements for grazing programs (FWS should examine its approaches for livestock management on refuges and its role in range management-related activities BLM should assess its heavy reliance on rest-rotation grazing in riparian/stream areas where rainfall is low).

We should encourage a policy to effectuate the synthesis of information on grazing, streams, and streamsides so the scattered information is made accessible to field workers of all agencies. We also need a policy of intensified information dissemination and technology transfer to the public, livestock interests, administrators, and resource agency personnel. This transfer of information should reach livestock managers operating on private lands.

A policy change is needed in all government sectors to guarantee dedication to compliance and implementation of the laws and agreements covering these issues; range managers have sufficient laws and guidelines to improve range conditions--these tools should be used.

First priority among suggested policy-change recommendations would be an analysis of agency compliance or lack of compliance with laws and agreements pertaining to the management of riparian/stream habitat. Next would be the identification of funding limitations which prevent or hinder compliance with laws and agreements. The next priority would be the identification of the roles of specific agencies in cooperative efforts to solve problems, including research. Next would be approaches for training of personnel.

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Background Paper No. 7

DATA BASE ASSESSMENT OF EFFECTS OF AGRICULTURAL TECHNOLOGY ON SOIL MACROFAUNA AND THE RESULTANT FAUNAL IMPACT ON CROP AND RANGE PRODUCTIVITY

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ABSTRACT

Data Base Assessment of Effects of Agricultural Technology on Soil Macrofauna and the Resultant Faunal Impact on Crop and Range Productivity

by
Daniel L. Dindal
November 30, 1980

Biotic communities comprised of decomposer invertebrates inhabit most soils. Functioning together with soil microorganisms, decomposer invertebrates cause the decay of organic debris. As a result, nutrients and energy bound in organic matter may be made available to other organisms, or they may be cycled and/or pooled in some component of the soil ecosystem. During the processes of decomposition, humus is ultimately formed, and the physical as well as the chemical structure of the soil is modified and enhanced. With few exceptions, these soil fauna and their roles go unnoticed and not appreciated. This basic scarcity of knowledge is, therefore, one of the primary reasons the general data base associating soil macrofauna with agricultural practices and productivity is so lacking in the Unites States.

An assessment of the data on soil fauna related to agriculture in this country indicates the following reasons for the deficiency of information: 1) historically, soil biology has been investigated in Europe and Russia with more vigor and constancy over a longer period; 2) most ecological research on soil organisms has been conducted in forest soils; 3) the organization, traditions and practices employed in our agricultural program in this country precluded any need or interest for the support of soil invertebrate studies; 4) private and governmental support facilities for this discipline have been limiting in services; 5) in the past, no academic institutions in the U.S. offered courses in soil ecology; and finally 6) once a worker decides to pursue this area, procedures for research sampling, handling and analysing are found to be extremely tedious, rigorous and time consuming. Still in the midst of these problems a few soil biology centers have been established in this country. Interest is definitely growing.

In the future development of soil agroecosystem studies, the microcommunity approach should be adopted as the operational and conceptual framework from which community structure and function should be quantified. To facilitate adoption of this proposed specific methods for use in microcommunity analyses and comparison of treated and control sites are presented. Likewise, sources of the most recent taxonomic aids are given.

When considering the basic lack of knowledge of available information and the problems outlined above in the general assessment part of this report, the data base for agricultural soil ecology is in an early alpha stage of development. This first half of this report, therefore, explores in detail the growing pains which should ultimately lead to valid, effective data base development.

The latter half of the report reveiws a small part of the relevant literature from foreign countries. Furthermore, results from the isolated studies in the U.S. are interspersed with foreign data. Attempts were made to resolve some of the weaknesses between the two geographic data sources by suggesting potential research hypotheses related to specific agricultural practice. If investigated to their fullest, these hypotheses should finally help provide the baseline data required to synthesize sound concepts, principles and a degree of reasonable predictability about rates and interactions between soil fauna and agricultural productivity.

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I. INTRODUCTION

Most all soils, the world over, are inhabited by a diversity of life forms. Although usually quite subtle, these soil organisms are very dynamic and often characteristic to the particular soil in which they are found. Numerous bacteria, molds, actinomycetes, a very wide variety of invertebrate animals and a few vertebrates comprise the soil biota. Most of the soil invertebrates are microscopic or, at the most, very tiny to the naked eye. Some of the larger soil invertebrates such as earthworms, ants, other soil insects, and land snails and slugs are quite familar since they have been seen by most everyone. Small mammals are the dominant vertebrate animals found below ground while some amphibians, reptiles and even a few birds live at least a part of their life period within soils. As implied above, with the exception of some of the larger soil inhabitants the average person never sees or realizes that these soil denizens exist. And more unfortunately, few people realize the importance of life activities of the total community of soil organisms. Collectively, soil organisms modify the soil by their activities and furthermore their bodies provide microsites, the proper tissues and the catalysts for many physical and chemical processes that are vital to the formation and maintenance of the natural soil system. Even though these processes have occurred for eons and continue to occur today they go unnoticed to but a few.

SOIL FAUNA DEFINED

When speaking of the types of soil biota, soil biologists presently use the terms soil microorganisms, soil invertebrates and soil vertebrates.

The terms microbiota and macrobiota are only used in a very general way usually in reference to size. Microorganisms refer specifically to bacteria, molds (Fungi) and actinomycetes; soil protozoa are also included among soil microorganisms by most soil biologists. The soil microorganisms are the subject of a separate assessment report, while this treatise concentrates predominantly on invertebrates with some mention of the influence of vertebrates upon soils. Soil microorganisms will, however, be referred to occasionally since many close interactions exist between them and the soil invertebrates.

The term, soil invertebrates, includes a wide array and diversity of forms ranging from 1) the microfauna - microscopic rotifers, roundworms (nematodes) and very small mites; 2) the mesofauna - larger mites, pseudoscorpions, springtails (primitive insects known as Collembola) and small beetles and flies; and 3) macrofauna - earthworms, sowbugs, millipedes, centipedes, soil spiders, ants, termites, large beetles, small mammals and other soil inhabiting vertebrates. Oftentimes the term, microarthropods is used by soil biologists to refer to both the small and large mites and all of the other mesofauna collectively.

ABUNDANCE, BIOMASS AND DIVERSITY OF SOIL INVERTEBRATES

Although soil invertebrates are ubiquitous in distribution, studies to date show generally that the abundance of these creatures differ dependent upon the types of vegetational communities present and the associated organic matter complexes of the soils (Table 1).

The actual numbers of soil organisms found per unit volume of soil are astonishing! Of considerable surprise and interest to many, the abundance of nematodes surpasses all other faunal groups. Second and third in dominance are the mites (Acarina) and the springtails. Soil forms that are well known to the common person comprise a very low numerical proportion of the total soil fauna.

Table 1: COMPARATIVE ABUNDANCES OF SOIL ORGANISMS (average no/m^2)

			(Wallwork 1970, Cragg 1961)					(Bornebusch 1930)					(Huhta et al. 1967)	
			MOOR HOUSE, ENGLAND					DENMARK					FINLAND	
TAXA	COMMON NAMES	OLD FIELD (15 cm deep) SWITZERLAND (Macfadyen 1957)	LIMESTONE GRASSLAND	*Juncus* MOOR	*Nardus* GRASSLAND	MIXED MOOR	BARE PEAT	OAK FOREST MULL	BEECH FOREST MULL	BEECH FOREST MOR	SPRUCE FOREST MULL	SPRUCE FOREST MOR	CONIFER FOREST MOR	CONIFER FOREST MODER
BACTERIA $(\times 10^{12})$		1.5-4.3												
PROTOZOA, TESTACIDA $(\times 10^{9})$	SHELLED AMOEBAE	0.1-0.5												
NEMATODA (10^{6})	ROUNDWORMS	1.8-120	1.8-2.9	1.4-6.5	0.8-5.7	0.5-2.3	≤ 0.04						0.91-1.3	1.52
ROTIFERA	ROTIFERS	2500-7100												
MOLLUSCA, GASTROPODA	LAND SNAILS & SLUGS	100-8500						68	105	52	4	2		
ANNELIDA $(\times 10^{3})$														
ENCHYTRAEIDAE	POTWORMS	0.2-2	10-25	130-290	37-200	?	12-50	0.34	0.53	0.78	0.04	0.26	9.1-14.5	17.25
LUMBRICIDAE	EARTHWORMS	30-2000	389	?	<12	<1	0	122	177	81	101	18	0.3-28.9	57
TARDIGRADA	WATER BEARS	500-16000												
ISOPODA	SOW BUGS/PILL BUGS	100-400						283	149	53	1	0		
OPILIONES	DADDY LONG-LEGS	2-38												
ARANEAE	SPIDERS	180-840						181	178	379	215	231		
ACARINA $(\times 10^{3})$	MITES	20-120	45.3	43	77.8	65.8	0	0.97	3.21	6.16	7.34	7.83	112-234	258
MYRIAPODA	MILLIPEDES/CENTIPEDES	900-1700						110	177	39	10	2		
COLLEMBOLA $(\times 10^{3})$	SPRINGTAILS	10-40	77.9	38.9	55.9	42.3	0	0.493	1.198	5.114	2.210	1.702	14.7-34.3	25.4
FORMICIDAE	ANTS	200-500												
COLEOPTERA	BEETLES													
ADULTS		500-1000						141	234	426	113	325	5.1-97	79.1
LARVAE													22.4-56	55.1
DIPTERA · LARVAE	FLY MAGGOTS	1000	49	111-1418	?	41-385	0	271	232	1076	757	336	10.7-26.9	69

Equally as interesting is the relative biomass of the various soil organisms (Table 2). The weight of soil microflora per unit volume of soil far surpasses that of the total soil invertebrates. Among the soil invertebrates, earthworms usually provide the most biomass followed by arthropods. Compared further, the biomass of humans per unit area in the Unites States (Table 3) appears so insignificant relative to that of soil microorganisms, soil invertebrates and plants (Pimentel et al. 1980). Based upon these compared weights it is quite obvious just what terrestrial organisms should be studied to a greater extent in order to better understand the environmental quality of our country.

The species variety (or richness) and the relative distribution of the individuals among the species present (known as the equitability or evenness) comprise the diversity of organisms in any given site. Soils under tropical rain forests, deciduous hardwood forests and grasslands particularly over calcareous-rich parent material usually possess the greatest diversity of soil invertebrates. These soils are species rich and the equitability is very high, that is the number of individuals in each species is almost equal. In contrast, soil invertebrate diversity decreases relatively in coniferous forest soils and old field soils. And finally, peat areas, sandy soils and soils in beach-dune successions exhibit the least diversity. The latter sites have a low diversity because fewer species are present and of those present only several species will be represented by many individuals while the remainder will be rare perhaps only with one or two individual representatives. Thus low richness as well as a low degree of evenness are exhibited. As will be shown later human activities can cause very dramatic shifts in soil invertebrate diversity, equitability and richness. This may occur without actually changing the total numbers of invertebrates present. If this happens, the specific ecological functions of the soil

Table 2: COMPARATIVE BIOMASS OF SOIL ORGANISMS (gm/m^2)

TAXA	COMMON NAMES	OLD FIELD (15 cm deep) SWITZERLAND (Stockli 1952)	(Bornebusch 1930) DENMARK					(Volz 1950) WEST GERMANY		DECIDUOUS FOREST ENGLAND (dry wgt) (Satchell 1971, Gray, Hissett, Duxbury 1974)
			OAK FOREST MULL	BEECH FOREST MULL	BEECH FOREST MOR	SPRUCE FOREST MULL	SPRUCE FOREST MOR	BEECH FOREST MOR (25 cm deep)	OAK FOREST · MULL (25 cm deep)	
BACTERIA		2022								3.69
ACTINOMYCETES										0.02
FUNGI	MOLDS/YEAST									45.40
PROTOZOA, TESTACIA	SHELLED AMOEBAE	38						0.87	0.58	0.10
NEMATODA	ROUNDWORMS	5						4.05	15.15	0.20
MOLLUSCA, GASTROPODA	LAND SNAILS & SLUGS		5.3	4.9	3.2	0.2	0.1			0.50
ENCHYTRAEIDAE	POTWORMS	1.5	0.7	1.1	1.6	0.02	0.1			0.40
LUMBRICIDAE	EARTHWORMS	400	61	53.1	5.4	5.1	0.9	2.02	24.80	1.20
ISOPODA	PILL BUGS/ SOW BUGS	79.1	0.3	0.1	0.05	0	0			0.60
OPILIONES	DADDY LONG-LEGS									
MYRIAPODA	MILLIPEDES/ CENTIPEDES		4.7	7.5	1.1	0.4	0.1			
ARANEAE	SPIDERS		0.8	1.5	1.1	0.9	1.1			
FORMICIDAE	ANTS									
COLEOPTERA	BEETLES		0.7	0.8	4.0	2.2	4.8	8.61	0	
ADULTS										
LARVAE										
DIPTERA LARVAE	FLY MAGGOTS		3.1	1.5	7.0	1.5	4.3			0.30
ACARINA	MITES	1.1	0.1	0.2	0.3	0.4	0.6	1.82	2.77	0.10
COLLEMBOLA	SPRINGTAILS		0.1	0.1	0.2	0.1	0.1			0.20
			76.8	70.8	23.9	10.8	12.1			

Table 3: BIOMASS COMPARISONS OF NATURAL TERRESTRIAL BIOTA WITH THAT OF HUMANS AND LIVESTOCK IN THE UNITED STATES.

TAXA	AVERAGE BIOMASS (kg/ha live wgt)
BACTERIA	1700
FUNGI	2700
ALGAE	150
PROTOZOA	150
PLANTS	55000
EARTHWORMS	1000
ARTHROPODS	1000
BIRDS	~18
MAMMALS (WILD)	~18
LIVESTOCK (DOMESTIC)	90
HUMANS	18

(after Pimentel et al. 1980)

fauna in a site are altered.

ECOLOGICAL FUNCTIONS OF SOIL INVERTEBRATES

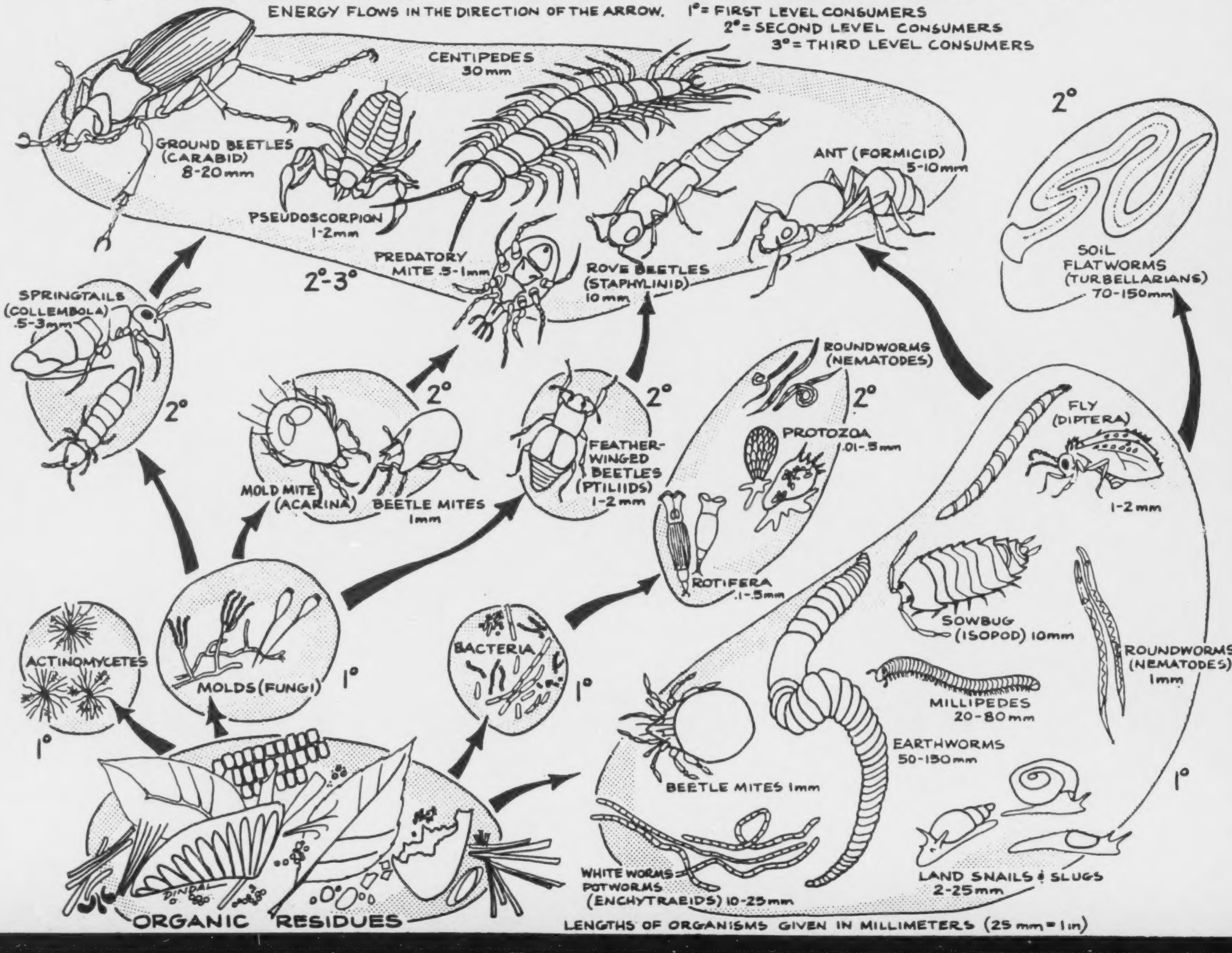
Decomposers. The ultimate direct or indirect function of soil biota is the physical and chemical decomposition of all types of organic debris (mostly non-recalcitrant) deposited on or within the soil. Recognizable organic materials are thus reduced in size and changed chemically by the interactions of the soil flora and fauna. These creatures are the decomposers of the soil. In time, the biologically altered organic substances become part of the polymerized matrix of complex compounds known as humus and soil organic matter. Most of the humification, especially in its final stages, is carried out via the biochemical processing of organic matter by soil microorganisms, whereas, the early stages, such as the physical decomposition are initiated and reworked sequentially by the soil invertebrates. The successive breakdown in organic matter particle sizes, known as comminution, results from ingestion, digestion, assimilation, and excretion by the invertebrates. Most soil invertebrates act also as carriers of microbial propagules, thus inoculating the organic matter as it is being processed through their bodies. Furthermore, fecal pellets of larger invertebrates are consumed by smaller soil animals causing additional chemical decomposition and even more reduction in particle sizes of organic matter. As organic particle comminution advances, the surface area is increased and thus becomes more accessible to the activities of the more minute soil microorganisms. Nutrients and various chemical compounds bound in the organic debris are released as decomposition proceeds, and they either become available to the higher plants and animals in the ecosystem or they are again bound temporarily within the tissues of the soil flora and fauna or onto chemically active sites on the soil organic matter. Hypothetically, therefore, fewer chemical elements are lost by leaching from sites where soil biota and organic matter are abundant.

Energy Fluxes. In addition to this natural nutrient recycling system, energy from organic debris is cycled and recycled through the bodies and tissues of the soil biota where it provides the power for vital decomposition activities. Details of this energy flow as it relates to the creatures in a compost pile are given in Figure 1 (from Dindal 1971). Since organic litter is merely natural compost, these organisms and their relationships as illustrated here are the same in most soil systems which are rich in organic materials. Heat energy produced by the metabolic processes of soil organisms can also play an important role in soils that are insulated by snow cover and/or leaf litter and those that are not frozen solid. The heat dissipates from the biota in the form of infrared radiation into the surrounding soil microhabitats. With these natural layers of insulation, this added heat energy source plus the lowered freezing point due to the water-clay and water-protein soil complexes, a condition of extended biological activity is maintained in soil microsites during cold periods.

Soil structural changes. Concurrent with the production of humus and the recycling of nutrients, compounds and energy, soil organisms of the decomposer food web are also responsible directly or indirectly for 1) the incorporation of the mineral soil with the decomposed organic matter, 2) the increase of water-holding capacity, 3) the enhancement of soil aggregation by the production and dissemination of gums and mucopolysaccharide complexes, and 4) the stimulation of soil porosity accompanied by a decrease in bulk density.

Finally, from an ecological viewpoint all the soil decomposers, both microorganisms and invertebrates function in a highly interrelated way to assert very significant effects on the formation, characteristics and maintenance of the uppermost soil horizons.

Figure 1: FOOD WEB OF THE COMPOST PILE (Dindal 1971)


ENERGY FLOWS IN THE DIRECTION OF THE ARROW.
1° = FIRST LEVEL CONSUMERS
2° = SECOND LEVEL CONSUMERS
3° = THIRD LEVEL CONSUMERS
CENTIPEDES 30mm
GROUND BEETLES (CARABID) 8-20mm
PSEUDOSCORPION 1-2mm
PREDATORY MITE .5-1mm
ROVE BEETLES (STAPHYLINID) 10mm
ANT (FORMICID) 5-10mm
2°-3°
2°
SOIL FLATWORMS (TURBELLARIANS) 70-150mm
SPRINGTAILS (COLLEMBOLA) .5-3mm
2°
MOLD MITE (ACARINA)
BEETLE MITES 1mm
2°
FEATHER-WINGED BEETLES (PTILIIDS) 1-2mm
2°
ROUNDWORMS (NEMATODES)
2°
PROTOZOA .01-.5mm
ROTIFERA .1-.5mm
FLY (DIPTERA) 1-2mm
ACTINOMYCETES
1°
MOLDS (FUNGI)
1°
BACTERIA
1°
SOWBUG (ISOPOD) 10mm
ROUNDWORMS (NEMATODES) 1mm
MILLIPEDES 20-80mm
EARTHWORMS 50-150mm
BEETLE MITES 1mm
1°
LAND SNAILS & SLUGS 2-25mm
WHITE WORMS POTWORMS (ENCHYTRAEIDS) 10-25mm
DINDAL
ORGANIC RESIDUES
LENGTHS OF ORGANISMS GIVEN IN MILLIMETERS (25 mm = 1 in)

II. STATUS OF RESEARCH FACILITIES AND GATHERING OF SOIL MACROBIOTIC DATA

SOIL BIOLOGY: AN INFANT IN THE UNITED STATES

Historically, most research on the biology and ecology of soil invertebrates was carried out in Europe and Russia; although there were occasional American publications on soil organisms before the late 1960's, it was not until that time that a major effort and research thrust was initiated in this country. Even to the present day very few U.S. colleges and universities offer any courses in soil biology. In fact, many of the general functions of soil invertebrates as presented above have been compiled predominantly from the works of foreign scientists.

As with so many fields of biological inquiry, Darwin in 1881, initiated studies in England on experimental soil biology dealing with earthworms. His studies stimulated further studies in Europe. To this day Darwin's lead is of interest and is cited by earthworm researchers everywhere.

Later in 1905, A. Berlese in Italy, paved the way for the study of soil arthropods with his research and development of a mundane but rather effective apparatus for extraction of these forms from soil and soil litter. Tullgren (1917) modified the Berlese funnel into the design that is still in use today. Rather quickly Europeans adopted the use of the Berlese-Tullgren apparatus for studies on the taxonomy and ecology of soil invertebrates. With the exception of the hiatus during the war years research spread over the continent and the momentum of these early workers was renewed and constantly expanded upon.

In America, for many years, soil biologists have been scattered geographically with very little communication with one another. Also, various general biologists have made collections and studied the taxonomy of all types of organisms including soil invertebrates. But many of these creatures remained undescribed or were merely named and deposited in museum collections. In several states, Illinois and Ohio for example, local biological agencies published survey lists on various soil forms such as earthworms (Smith 1895, 1896 and Olson 1928). Also in Kansas, Bryson (1933, 1939) studied ecological relationships between soil insects and the physical properties of soil. Soil biological research, however at best, has been extremely limited in our country. One scientist, A. P. Jacot, while in the employ of the U.S. Forest Service in North Carolina, concentrated his research and publications on an important group of soil mites, the oribatids. Oribatid mites feed primarily on soil fungi and organic debris. In addition to taxonomic contributions, Jacot provided much ecological information on invertebrate communities in soil under published titles such as "Wildlife of the forest carpet" (1935), "Soil structure and soil biology (1936)," "Why study the fauna of the the litter? (1936)," "Evolutionary trends, ecological notes and terminology of the large-winged mites of North America" (1937), and "The fauna of the soil (1940)."

A contemporary of Jacot, W.P. Taylor working with the Bureau of Biological Survey (USDA) in Arizona, published a good overview in 1935 of the animal relations to soil. Although Taylor mentioned the importance of Darwin's earthworm work and also the value of ants and subterranean termites, he concentrated mainly on the effects of mammals on soil. In 1949, J. Thorp working with the Division of Soils (USDA) in Nebraska presented an evaluation of the effects of the same type of animals on the soils with which he dealt. Also, during this period from 1946 to 1949, H. Hopp and his coworkers (USDA) published some of the only data available to date in this country on the effects of agricultural practices on earthworms. Other than the results from these workers, research in soil invertebrate zoology has proceeded very slowly or sporadically compared to the patterns of foreign research during the same time period.

Even with the strong leads by the aforementioned early Federal employees and state bureaus the continued committment by our government agencies to conduct research on the benefits of soil fauna has been a very, very low priority item with the U.S. Bridging the time gap between the Jacot-Taylor-Hopp-Thorp era and the mid-sixties, I know of only one Federally mandated position where extensive research on soil invertebrate ecology was specified. That was a Forest Service pioneering unit project comprised of one worker, Dr. L.J. Metz at Research Triangle Park, NC. Unfortunately, he retired in 1979, and the project has been inactivated effective 1980. During his tenure Metz opened his laboratory to several soil biologists, and they published widely on a variety of soil ecological topics. He was truly a pioneer in the field doing much to maintain the discipline of soil invertebrate ecology, and his work is respected throughout the world.

SOIL BIOLOGY CENTERS ARE BORN

Eventually by the early sixties isolated academic workers initiated soil faunal studies; several other soil ecological programs were developing around several faculty and a nucleus of graduate students at University of Michigan and Michigan State University. A soil biology program was organized at the Oak Ridge National Laboratory (ORNL) directed by S.I. Auerbach, D.A. Crossley and D.E. Reichle. Finally by 1965-1967 several rather permanent centers were organized where usually a team of staff scientists investigated problems in soil ecology. At that time D.A. Crossley moved to University of Georgia (UGA) and spearheaded a program which is still very dynamic. C.A. Edwards, renowned soil ecologist from Great Britain's Rothamsted Agricultural Experimental Station, spent several years as a visiting professor at Purdue University in the late sixties and activated a pulse of interest in that region. Auerbach and Reichle along with M. Witcamp and B. Ausmus at ORNL proceeded to develop their soil biology program stimulating much interest through the mid-seventies. Cooperative soil biological studies were organized at ORNL and UGA. D. Coleman, soil ecologist with experience from ORNL and the Savannah River AEC Laboratory, moved to Colorado State University (CSU) where he also established a considerably important research program in the soil biology of the grasslands in the Great Plains; his program is still quite active.

Another center was organized on our campus in 1966, following research activities started by L. Stegeman. When I was hired by the State University of New York College of Environmental Science and Forestry I was charged with further developing a teaching-research program in soil biology. Under that directive I have hosted six annual Soil Microcommunities Conferences, and in 1979 I hosted the VII International Colloquium on Soil Zoology on our campus. The attendance of the latter meeting included 135 scientists from 27 countries, 5 Canadian provinces and 19 states. This was the first time such an international meeting on this topic was ever held in this hemisphere. Also a national Soil Biology Society is being organized by our efforts. This society and the annual meetings have been developed to encourage cooperation and communication among isolated workers and soil biology centers. In addition, we have developed a Soil Ecology Concentration area under the support of seven full-time faculty members. They are R. Hartenstein (soil physiology), M.J. Mitchell (soil bioenergetics and decomposition), J. Nakas (soil microbial ecology), R. Norton (soil invertebrate taxonomy), J. Wang (soil fungal taxonomy and physiology), R. Zabel (wood decomposition) and myself (soil community ecology). Through this organizational vehicle both the basic scientific aspects as well as the applied facets of soil biology are being encountered and pursued.

NON-AGRICULTURAL DATA DOMINATES

In the past, most of the publications on soil invertebrate ecology in this country and abroad have been concentrated on forest soils. Of the few exceptions are the papers on earthworms by Hopp (1946), Hopp and Linder (1947) and Hopp and Slater (1949). Generally, however, life within agricultural soils appeared to be of little concern to soil biologists for about 30 years. Also, few agriculturalists and agronomists were interested in soil biology. Several reasons seemingly accounted for this attitude. Most agricultural practices, especially in the U.S., were not developed or geared in such a way as to work in unison with soil organisms. Soil was thought of and treated only as a substrate - a culture medium to be manipulated physically and chemically for maximum production. The manipulative practices on agricultural soils were quite drastic and caused extremely rigorous microenvironments relative to soil fauna. Obviously, the past methods for accomplishing high productivity of food and fiber cannot be faulted completely. Human existence has been much more comfortable and culturally, educationally and financially profitable because of our past agrotechnological practices. However, the technical modes of maximizing productivity such as they have been definitely have predisposed and controlled the nature and funding of soils research. The natural presence and natural functional role of soil animals in agricultural soil has not been studied enough to determine the total potential benefits of these creatures and their possible symbiotic relationships with mankind. Data from forest soils have been exciting to collect and analyse, and they provide many sound foundations on which to propose and test hypotheses related to agriculturally dominated areas. However, interest in agriculturally oriented research in soil ecology has been limited probably due mostly to a lack of research funding committments.

AN AGRICULTURAL BEGINNING

Foreign Findings. In England, between 1843 and 1856 Lawes and Gilbert started eight agricultural experimental plantings known as "the Rothamsted Classical Experiments" in the Broadbalk fields; thus the Rothamsted Experimental Station, the oldest agricultural research station in the world, was founded (anon. 1974). These classical experiments are still in existence - 137 years later. Various controlled agricultural practices have been conducted and all responses have been closely monitored and recorded. Since the mid-fifties Dr. C.A. Edwards investigated soil fauna in these fields as well as other arable sites on the Station. In 1960, he and E.B. Dennis published on insecticide effects on soil forms, and this was only the beginning of his numerous papers related to pesticide activity on non-target soil animals. Edwards further studied the effects of manure and fertilizer applications on soil organisms in the Broadbalk fields as well as comparisons of no-till with standard cultivation practices. A major bulk of data on the agriculture-soil faunal relationships continues to emanate from the laboratory of Edwards and colleagues. Details will be summarized later in various sections. Although some important information from Rothamsted is applicable in our country, many of the farming practices are somewhat different and carried out on a much smaller scale than in the U.S.

Research in soil biology related to agriculture has also blossomed in India within the last 10 years, mainly due to the influence of C.A. Edwards. He has propagated his interests through many research and teaching visits. An Indian Society of Soil Biology and Ecology has been chartered as well as the establishment of the Indian Journal of Soil Biology and Ecology. Research interest in soil invertebrate ecology is rapidly spreading throughout all the regions of that country. Already the proceedings of two of their annual symposia on soil biology have been published (Edwards and Veeresh 1978, Edwards, Veeresh and

Krueger 1980).

Another major source of contributions on the effects of agriculture on soil fauna originated in the USSR under the leadership of Prof. M.S. Ghilarov. His first monograph on soil animals was published in 1949, followed by at least a paper per year on soil biology. In 1965, Ghilarov presented a comprehensive review on practical applications of soil zoology mostly associated with agricultural conditions. Concurrent with Ghilarov's work, and probably stimulated by him, there has been an upsurge of many agricultural-soil biology projects in various regions of Russia and in the other communist bloc countries including Czechoslovakia, Poland, Yugoslavia, Lithuanian SSR and Latvian SSR.

Our Single Factor, Economic Emphasis. Even though studies in soil ecology in the U.S. are behind those in Europe and Asia, work on fauna associated with American agricultural practices is beginning. Presently, however, our data base for agricultural soil biology is very narrow. Isolated economic problems such as a pest condition involving a soil inhabiting species have usually been and still are oftentimes the only stimuli for research on soil forms. Therefore, economically oriented projects are frequently the only ones that have been adequately funded. Too often, in our country the single factor approach to a complex problem is undertaken for a quick answer. As soon as that immediate economically important factor is identified and dealt with the investigation ceases. However, as one problem is solved, many times others are created which remain ignored until an answer is imperative. Most of the time a total ecological approach could have been efficiently and effectively considered in the context of the original problem.

Farsighted research approaches in soil biology such as long term field comparisons, multiple factor procedures and the more ecologically oriented studies could lead to new hypotheses and understanding of many important interaction dynamics. For example, various species of plant parasitic nematodes have been studied individually for many years relative to their specific hosts and control mechanisms within the framework of our monocultural farming practices. When the total communities of soil nematode species in agricultural and undisturbed land were studied and compared in California, a very interesting finding was made. In natural and undisturbed soil systems, less than 35% of the nematodes were plant parasitic; after soils have been disturbed and cultivated the numbers of plant parasitic roundworms increased far beyond the 35% level (H. Ferris 1980, pers. comm.). In both cases the remainder of the nematodes were free-living feeding upon types of decomposing matter, bacteria, fungal spores or preying upon each other and other microfauna. Thus in natural sites the majority of the roundworms either aid in soil organic matter incorporation as decomposers or, as predators they are natural agents of biological control. Knowing these facts, sites with parasitic nematode problems could be advantageously manipulated, perhaps employing no-till for a season in a rotation or some other practice that leaves the site relatively undisturbed for an advantageous period of soil nematode community adjustment.

Another example is apparent in our recent effort to be farsighted and suggest a quick answer regarding our future energy needs; the lack of knowledge of soil ecology among some scientists in our country was again vividly reflected. The gathering and utilization of all crop residues, forest litter and organic matter is proposed as a constant and abundant source for alcohol and ultimately gasohol production (Abelson 1980). Fortunately, and to his intellectual credit, Professor Hans Jenny (1980), of the University of California, responded to the suggested indiscriminate conversion of biomass and organic wastes to fuels. He correctly states:

> "Production of biomass demands suitable combinations of climates and soils. For a soil

> to function effectively in plant production it must possess substantial water-holding and ion-exchange capacities, good physical structure, and thriving populations of bacteria, fungi and invertebrates. These attributes are highly correlated with humus substances, which are dark-brown organic macromolecules rich in phenolic compounds and are derived from plant remains and microbial synthesis. Humus has a high sorptive capacity for toxic metals, and its buffering power mitigates the impact of acid rain. Humus maintenance requires a steady influx of plant biomass from root decay and aboveground organic residues. Good soil structure depends on aggregation of colloidal clay platelets held in position by organic thread molecules. These are being consumed continually by invertebrates and have to be replenished by photosynthesis and microbial products . . . The carbon and nitrogen cycles of ecosystems will be curtailed and soil stability endangered. Because of a possible climatic warm-up, we do not wish to accelerate humus oxidation and the concomitant flux of carbon dioxide from soil into the atmosphere . . . The humus capital, which is substantial, deserves being maintained because good soils are a national asset."

Jenny's comments need to be heeded especially in the context of the importance of discovering and applying sound soil ecological principles.

Recent Assessment of Our Status. The theme of the International Colloquium on Soil Zoology held in Syracuse in 1979 was, "Soil biology as related to land-use practices;" of the 96 papers presented, 20 dealt with effects of agriculture on soil fauna. Only one paper of the latter 20 described work conducted in the U.S. Such a response by our scientists at an international forum held in our country reflects and amplifies the status of our comparative research involvement in soil faunal-agricultural studies.

RESEARCH SUPPORT FACILITIES IN THE UNITED STATES

Funding. No single funding source has been established to help support specific research in soil invertebrate ecology as related to agriculture. Since the ecology of the fauna in agricultural soils is considered to be a topic of an applied nature, such studies do not fall within the purview of certain of the Federal granting agencies. Some research associated with soil ecology of forest soils has been supported through Forestry Consortiums and the McIntire-Stennis programs of the USDA. Effects of municipal waste-water irrigation on soil fauna of all types of vegetative communities has been supported by the Office of Water Resource Technology (USDI). And National Science Foundation funds have been granted upon different occasions to support studies on soil invertebrate ecology of a more theoretical type. One of the most promising grants made in recent times by a Federal agency was that made to D.A. Crossley Jr. and R.L. Todd (UGA) by the Department of Energy for the comparative study of the effects of conventional and no-till agricultural practices on soil mesofauna, primary and secondary productivity, soil properties and nutrient cycling within the agroecosystems.

With the exception of those projects mentioned above, the general trend toward austerity budgeting adopted by national, state and local governments, funds for research in all disciplines in academic institutions are very lean or practically non-existent. Essentially the soil biologists' research programs have progressed very slowly; and since agricultural soil ecology has not been stressed in the past that area at the present time, unfortunately, shows very little promise in this country. Ironically at this time there is a great potential of educated and interested workers in the U.S. very eager to get involved in research in soil ecology, but they have had very little or no access to positions or funding. As a result the effects of agricultural technologies on soil macrobiota continues to advance only at a very slow rate. Hopefully, policymakers concerned with agricultural soil ecology may be able to help transmit the philosophy of necessity and implement modes of funding research on this vital area of environmental need.

Scientific Services. Most all phases of field ecological research must rely upon taxonomic support services. These are usually provided by major museums and agencies that depend partially or entirely on governmentally funded programs. The Smithsonian Institution is such a facility. In some cases very fine taxonomic information and verification services are provided by the Smithsonian staff for many groups of organisms. However, very few staff specialists are available in the taxonomic or ecological fields dealing with forms of soil micro- and macrobiota. Two individuals, E. Baker and R. Smiley, working for the USDA in cooperation with the Smithsonian are the only Federal specialists in mite taxonomy; their major responsibilities deal with various facets of economic acarology namely the recovery, identification, assay and possible quarantine related to potential mite pest introduction problems. Even with these all encompassing duties they do assist when they can in soil acarine related questions. In addition, no staff specialists on either Collembola or earthworms are employed at the Smithsonian. As indicated in Tables 1-3 mites and collembolans are numerical dominants and earthworms are biomass dominants in most soils and are therefore extremely important in the functional dynamics of the soil ecosystem. Even the most numerically dominant invertebrate group in practically all soils- the nematodes - are represented only by specialists in plant and domestic animal parasitic forms; free-living forms appear to be considered only marginally. The nematode parasitologists at Beltsville do excellent work, but colleagues dealing solely with free-living forms related to agriculture and decomposition are needed.

Finally, what has been most disturbing to a number of soil invertebrate ecologists is the rather routine refusal by some members of the Smithsonian staff to aid in verification of specimens of their taxonomic speciality that soil ecologists encounter during their research. Interestingly, a number of

U.S scientists dealing in soil ecology obtain their best verification services and the most welcome taxonomic advice from the Biosystematics Research Institute of Agriculture Canada! It is unfortunate that our own institutions cannot be of more assistance.

III. OVERVIEW OF AVAILABLE DATA BASE: INTERRELATIONSHIPS OF AGRICULTURAL PRACTICES AND MACROBIOTA OF SOIL

A. General Status Within the United States

SOIL INVERTEBRATE SURVEYS

No completely valid and predictable models relating components of agricultural soil ecology are available or can be made at present. Nor can applicable agroecological rates be determined for our country until more basic, accurate soil faunal survey data has been accumulated.

The Basic Shock. For all practical purposes, scientists in the U.S. have just started to conduct accurate research on interactions between agricultural practices and soil invertebrate ecology. Some records of types and numbers of soil animals associated with very general soil types and vegetative types have been made. But many more surveys from various areas of the U.S. are necessary in order to provide baseline information on which environmental manipulations and modifications, like farming, can be assessed. With this important necessity in mind a number of tedious problems characteristic of soil invertebrate ecological work must be confronted. First, to gain appropriate agricultural-soil invertebrate impact data, many, generally ten or more per site, small samples must be taken from treated and comparable control areas over at least a year's period. Early surveys were grossly incomplete since they were based upon a single sample accompanied by no control taken at some convenient time perhaps in mid-summer. Ideally, agroecosystem data dealing with new practices should be collected over three or four years'periods to have a minimal, reasonable data base for comparison with old practices or control sites. Maintenance of small, multiple sampling is vital to attain measures of seasonal variability. These multiple samples for soil faunal assays should not be pooled and then subsampled even though this is a traditional collection method in agronomy. Biological variation must be calculated for ranges of variability values have been found to differ significantly between treated and untreated sites (Dindal, unpublished). Also, many soil animals, particularly microarthropods (Hartenstein 1961), nematodes and some macroarthropods (Cole 1946) exhibit a clumped (contagious or negative bionomial) distribution which makes variation evaluations within species very important.

Secondly, very few croplands have ever been sampled for soil fauna because the regular disturbance associated with plowing, planting, cultivation and harvests appears as an unmanageable hindrance to uniform collections. Field data are therefore at a premium.

Thirdly, the sheer numbers of soil organisms per sample can become overwhelming to assess. For example, a soil core sample, 5 cm in diameter by 3 cm deep, from a Crosby silt loam in a 20 year old Central Ohio old field may have a range of 30 to 1000 individual microarthropods within it! Multiplying these types of findings by 1440 samples taken monthly for three years, the total of 720,000 individual creatures is staggering (Dindal, Folts and Norton 1975).

This latter situation quickly leads directly into the fourth tedious problem, that of sorting, counting, identifying and determining ecological roles of these creatures. This demands extreme patience and technical intelligence. But to further complicate and illustrate once again the infancy status of this science, between 5% and 25% of the microarthropods found on most new sites studied will be new species - never before described taxonomically!

And quite possibly they have never been even seen before! Adding trauma to an already confounded condition, the available taxonomic keys for identification of soil biota have been European or Russian in origin, and they do not adequately apply to many of the unique U.S. fauna. Needless to say, life history details and trophic level strategies of these new forms are also unknown, and each demands proper laboratory and field consideration.

Finally, not all facts about the soil and information about fauna comprising a given soil invertebrate community can be obtained from the same sample. Separate sampling schemes must, therefore, be used to obtain the following; microarthropods, nematodes, earthworms, potworms, protozoa and macroinvertebrates. Numbers of samples can quickly become multiples of six depending upon the thoroughness of the soil community evaluation.

The necessity to be aware of all these problems has discouraged many prospective researcher in soil ecology and basically becomes a very realistic constraint on accumulating data. Dealing with such tedium characteristic to this discipline requires highly trained and dedicated technical research staff members. The soil ecology centers mentioned above provide excellent training; an adequate funding base is needed for center support and maintenance of a dedicated staff.

A Land of Unknown Worms. When first informed, few people believe that the native earthworms of the U.S. are essentially scientifically unknown! Of course, many worms are confronted and recognized on sight. However, these familiar creatures most common to the more northern areas of the country are all of the family Lumbricidae and because of their anthrophilic nature, they were all introduced from Europe with early colonists. Since there had been much early research on the lumbricids in Europe, that knowledge also followed them across the sea. Although far from adequate as related to the U.S. environments, data on lumbricids far surpasses any available on our endemic earthworm species. To date not even an adequate identification key is available. Earthworms are biomass dominants wherever they are found, and based upon studies with lumbricids these creatures are one of the most ecologically beneficial beasts in the soil world. A comprehensive study of our native forms and further research on our introduced forms is imperative if we are to even pretend to understand their total impact in agroecosystems and other lands devoted to other types of productivity.

SOIL ORGANISM IDENTIFICATION

Soil biota are among the least well known taxonomically of the creatures of the world. Perhaps less than 60% of the mites of the world have been identified (G.W. Wharton, pers. comm.). In the taxonomic area of soil biology, again the Europeans and Russians have made major strides when compared to our impact. We have floundered in our effort to use European sources for identification of U.S. species and have been generally unsuccessful. But there is brightness on the taxonomic horizon for soil ecologists in North America. The most important applicable sources books for soil invertebrate identification plus some ecological data are or will be as follows:

ACARINA (mites)	Krantz, G. W. 1978. Manual of Acarology. (2nd ed). Oregon State Univ. Book Stores, Inc. Corvallis. 509 pp.
COLLEMBOLA (springtails)	Christiansen, K and P.F. Bellinger. 1980. Collembola of North America (Parts 1 & 2). Published by Grinnell College, Grinnell, Iowa.
LUMBRICIDAE (earthworms)	Reynolds, J.W. 1977. The Earthworms (Lumbricidae and Sparganophilidae) of Ontario. Life Sci. Misc. Pub., R. Ont. Mus. Toronto. 141 pp.
SOIL BIOTA (for naturalists, teachers, educated gardeners and farmers)	Dindal, D.L. 1981 (tentative). The Soil Lives: A primer to soil ecology. Rodale Press, Emmaus, PA. (in manuscript).

SOIL BIOTA (for students and researchers in soil biology)	Dindal, D.L. (editor). 1982 (tentative). The Soil Biology Guide. Wiley Publishing Co. NY (in manuscript; 46 chapters dealing with the dominant taxa of soil microorganisms and invertebrates, each written by a world specialist for application to North American biota; designed as a companion reference volume to Ward & Whipple's Fresh Water Biology also by Wiley Publishers).

All of these books have been designed to present the taxonomic and/or ecological "state of the art" related to the more common soil taxa. Widespread use of these volumes in the U.S. should assist in providing a common foundation on which and from which all soil ecologists in our country can start to accumulate a meaningful data base.

COMMUNITY STRUCTURE AND FUNCTION: FUTURE APPROACHES FOR AGRICULTURAL-SOIL ECOLOGICAL RESEARCH

Microcommunity Defined. After working 15 years in soil invertebrate ecology, I have found the biotic microcommunity concept to be the best approach to understanding, quantifying and comparing differences between treatment and control conditions in the field. In general, the community is the total living part of any given ecosystem. More specifically, Odum (1971) defines the biotic community as:

> "an assemblage (of biota [sic]) with unity of taxonomic composition, a relative uniform appearance and of a definite trophic organization and total metabolic pattern."

The biotic *macrocommunity*, such as a beech-maple forest, alfalfa field, old field herbaceous site, tropical rain forest or coral reef, is the basic structural and functional unit from which most ecologists study the living world. For a number of years I taught and conducted research in macrocommunity ecology before working on the microfauna of the soil. Concentrating in the latter area it soon appeared that all macrocommunities were comprised of smaller potential units of study. These component parts were structurally and functionally similar on a microscale no matter from what type of macrocommunity they were found. For example, finding dung in any type of environment, the specific microhabitat of the fecal material will always support a heterotrophic microcommunity of organisms which will basically be the same structurally and functionally. Based on these kinds of observations, I defined the microcommunity as an operational and conceptual approach for study (Dindal 1973). Furthermore, it appears that the total relationships and interactions of all types of microcommunities within a given macrocommunity account for the actual characteristic nature of the macrocommunity. For instance, one old field herbaceous community that is 10 years old may appear very similar to another that is 20 years old; the subtle differences, however, can be accounted for in a very manageable and more quantitative way using the microcommunity approach. Finally, this concept has applicability to agricultural sites as well as natural climax vegetative areas.

Structure and Function Defined. Various characteristics of species and interspecific composition (structure) and the corresponding dynamic features (function) of the species comprising biotic communities provide a logical format of parameters with which to study, quantify and compare all types of natural, disturbed and manipulated areas. Also, structural and functional aspects can be compared equally well in a valid way during short term as well as long-term environmental projects (Dickson and Dindal 1980). Detailed categories (Dindal, in press), most of which may be evaluated mathematically, are as follows:

Community Structure

Species diversity (number and/or biomass)
1. Species equitability (evenness)
2. Species richness
3. Species redundancy
4. Species dominance

- Symbiotic relationships (species associations)
- Habitat diversity (spatial heterogeneity)
- Similarity-dissimilarity indices
- Trophic level patterns
- Structural stability
- Seral stages (succession)

Community Function

- Community metabolism (autotrophy, heterotrophy)
- Productivity (primary, secondary)
- Energy flow (energy budgets)
- Ecological efficiency
- Niche dynamics
- Nutrient cycling
- Functional stability

A wide array of quantitative methods (too many to itemize for this presentation) have been proposed for each of these community categories. As with many mathematical treatments there are some disagreements mainly on theoretical bases as to what methods are best for each category. Part of the confusion on usage appears to relate to the fact that some of the theoretical approaches have never been tested with field data. However, a number of the structural and functional characteristics of soil invertebrate communities have been used successfully. Quantifications, comparisons and graphic analyses of data from control (untreated, UT) and treated (T) sites have been made on both the macrocommunity and microcommunity levels. References illustrating usage of these quantification methods in soil invertebrate ecology are as follows: Englemann 1961; Davis 1963; Berthet 1964; Macfadyen 1967; Reichle, Shanks and Crossley 1969; Clemen and Pedigo 1970; Edwards, Reichle and Crossley 1970; Johnson, Ferris and Ferris 1972; Johnson, Ferris and Ferris 1973; McBrayer, Reichle and Witcamp 1974; Dindal 1975; Dindal Folts and Norton 1975; Dindal, Schwert and Norton 1975; Metz and Dindal 1975; Norton and Dindal 1976; Dindal 1977; Dindal and Metz 1977; Dindal and Wray 1977; Dindal et al. 1977; Dindal 1979; Dindal, Newell and Moreau 1979; Dindal and Norton 1979; Huhta 1979; Metz and Dindal 1980; Tardiff and Dindal 1980; Stinner and Crossley 1980; Weems 1980; and Blumberg and Crossley *in review*.

Summary. It is hereby proposed that the concept of the microcommunity be employed in the assessment of the impact of agriculture on soil fauna. This concept should be used in concert with microcommunity structural and functional quantification methods to determine initially the data base regarding endemic soil invertebrates of the U.S. Secondly, these methods should be employed to assay the effects of macrobiotic changes on crop and rangeland productivity. Furthermore, researchers should be encouraged to apply their talents, their time and these methods in answering the many questions concerning agricultural-soil invertebrate ecological relationships.

B. Agricultural-Soil Ecology:World Status

Compiling research data on soil invertebrate ecology related to agricultural productivity from studies conducted around the world provides quite a mixture of results. Trends seen elsewhere can provide the basis for sound hypotheses to be tested in this country. Even though, care must be practiced to be certain that differing climatic factors, soil types, parent materials and cultural practices associated with the agriculture of a foreign area are taken into account when compared to a practice in the U.S. In all cases the following sub-topics to be treated in this section can be defined as general agricultural practices affecting soil fauna. In his book on *The Distribution and Diversity of Soil Fauna*, Wallwork (1976) devoted a chapter to effects of agriculture, and he stated the following two very basic categories for comparison:

DETRIMENTAL EFFECTS	BENEFICIAL EFFECTS
Plowing	Fertilizer applications
Crop culture	Drainage
Pesticide applications	Irrigation
Inorganic pollutants	Hedgerow management

He drew these conclusions from 52 references; all were European sources but five that were based on U.S. research. Interestingly, four of the latter dealt with pesticide effects. So with a degree of caution we can immediately develop from these categories some hypotheses to evaluate as we embark upon research in our land.

EFFECTS OF PHYSICAL DISRUPTION OF SOIL

Plowing. The two most obvious negative effects of this type of substrate disruption are the initial high mortality rates of soil fauna, and secondly the major alteration of the soil microhabitat due to removal of plants and litter layers (Wallwork 1976). Loss of plant cover and litter layers exposes the soil organisms to high variability and extremes in the microclimate. This may result in secondary effects of plowing, death or forced inactivity.

In a study in Michigan (Shaddy and Butcher 1977), T plots were plowed and double-disked and sampled for a summer. After the initial mortality, predatory mesostigmatid mites and a species of fungivorous beetle mites (oribatids) both increased in number and both moved to greater depths vertically in the T areas. One collembolan species, normally common in deeper soils was unaffected by T. Although Wallwork (1976) also states the possibility of these "beneficial" effects, still too little is known to determine what impact these fluctuations actually have not only on the soil community but on the productivity of the land. In addition, Shaddy and Butcher (1977) applied their plow-disk treatment to an old field (15 year old) that had an established herbaceous flora and an established soil microarthropod community on it. This T situation is not the same as testing a site that has been in a long term rotation or cultivation. The latter condition needs to be tested.

Relating annual plowing to the exposure of earthworms, Hopp and Linder

(1947) showed that a high proportion of worms die after the first frost of autumn. Kuhnelt (1961) suggests this could be alleviated somewhat by vegetative cover or mulch (Kuhnelt et al. 1976).

Edwards (1980) stated that earthworm populations are inversely proportional to the intensity of soil cultivation. Deep burrowing earthworm species like *Lumbricus terrestris* and *Allolobophora* (=*Aporrectodea*) *longa* are much more sensitive to cultivation's adverse effects; while the species comprising the *Allolobophora* (=*Aporrectodea*) *caliginosa* complex and *Allolobophora chlorotica* all increase with frequency of plowing. In general, the genus *Allolobophora* (=*Aporrectodea*) seems to be truly anthrophilic thriving in cultivated soils around cultivated plant roots (Gates 1972). The means by which these medium sized, very soft-bodied creatures can withstand the very abrasive abuse of plowing while other species cannot remains a mystery. Also, do these kinds of worms affect crop productivity? These two points remain to be answered.

Erosion. Earthworm populations were decreased to varying degrees dependent on the levels of erosion associated with different crops in hilly terrain in the Lithuanian SSR (Atlavinytė 1965). Over the three year study period, worms were actually carried away in the erosion water and soil worm loss decreased in percentage with time as follows: in turf 3.26 to 0.33%; in soil under perennials 5.67 to 0.68%; in fallow sites 22.43 to 1.84%; and in soil under barley and corn 5.2 to 2.91%. Although not mentioned specifically by Atlavinytė, the differential in percentages reflects possible species variability(thus different species vulnerability) associated with different cover types. Also earthworm losses from the fallowed sites, having been plowed only and left untilled and unsown in this hilly terrain, reflect the tremendous importance of vegetative cover in determining the actual physical maintenance of earthworm populations.

Compaction, trampling. Effects of domestic animal herds and machinery-both heavy farm implements and off-the-road vehicles-appear to impart a detrimental effect on the soil structure as well as soil invertebrate populations. Bayfield (1979) in Great Britain found that constant footpath trampling destroyed most of the larvae of the crane fly (Diptera, Tipulidae) in soil and litter. Crane fly larvae are important litter decomposers especially under wetter soil conditions. Garay et al. (1980) and Molfetas and Blandin (1980) all working in a beech forest near Paris reported that footpath trampling caused microarthropod densities to decrease from 150,000/m^2 (UT) to T densities of 7000/m^2. Litter macroarthropods were also greatly reduced with ants, pseudoscorpions, isopods and millipedes completely depleted; centipedes and spiders were reduced five fold. Both the richness and evenness components of species diversity were reduced, and species dominance was initiated.

Poinsot-Balaguer and Boigot (1980) showed that the impact of a horse herd in France notably modified the species diversity of the soil fauna, particularly decreasing the equitability. That is, the more advantageous community structure of high diversity with equality of species representation was shifted to a less stable community where several species of soil fauna dominated. Finally, Godfrey, Leatherman and Buckley (1978) and other investigators have suggested that the impact of even a single run by vehicles like a snowmobile may be sufficient to cause soil compaction problems and soil faunal reductions, however, no formal tests have been made or published on that point.

SPECIFIC CROP TYPE

Monocultural Effect. Since most agricultural practices have been developed for the primary productivity of a single crop species, one of the cosmopolitan responses has been the inducement of an associated arthropod monoculture, usually in the form of a pest species. The dominance of this pest will cause modifications of the biotic community by 1) competing with other species causing them to decrease or by 2) stimulating the growth of decomposer species that feed upon the pest's fecal material and molted skins or feed upon plant matter that has been knocked down by the pest. The usual human response of pesticide application further confounds the situation.

Differences in Litter. Soil faunal numbers and diversities are directly related to the amount and type of litter deposited on the soil surface during and after plant growth. Therefore, the biochemical and physical characteristics of crop species as well as the way humans harvest and utilize them all affect the soil community differently.

The influence of the physical properties and the amounts of litter was best illustrated experimentally by Gill (1969) working in an old field in Michigan. In addition to an UT old field herbaceous site, he used treatments of no litter, high amounts of litter and natural litter replaced with polyester dacron fiberfill. The latter was a nondecomposable substance that was physically but not biochemically similar to litter. After a 14 month period Gill found that high litter and the fiberfill sites were most similar in a relatively high abundance and distribution of microarthropods, especially during the summer and fall. The actual presence and the physical characteristics of litter were of major importance in determining presence of soil fauna in general. In an applied sense, sites are more advantageous to soil fauna where a maximum of crop residues like wheat stubble and corn stover are left. Faunal populations would also benefit from these factors under no-till conditions.

Although the increase of physical complexity of litter is of positive value to microarthropods generally, biochemical aspects of litter have also been shown to be important when considering particular species of soil microarthropods such as certain Collembola (Stevenson and Dindal, in review). Also millipedes, isopods, soil gastropods and earthworms responded positively to relatively high calcium levels in litter and low C/N ratios (Wallwork 1976, Bornebusch 1953, Lyford 1943 and Wittich 1942). The differences between legume litter (C/N = 10/1) with relatively low C/N ratio and wheat straw with a high C/N = 80/1 ratio provides considerably different microhabits. The legume litter will be colonized and decomposed much more quickly than the straw. Very different communities of soil fauna will result as the energy and nutrient from the legume tissue will be recycled more rapidly. Because of the slow decay rate associated with matter of high C/N ratios, the carbon and the few other nutrient elements present will remain pooled in the straw for some time.

Plant-Faunal Species Specificity. Not only is there a potential for certain invertebrate species to be associated with certain types of litter, but also a species specificity between soil fauna and plant rhizospheres seems highly probable. Only incidental faunal-rhizosphere associations have been noted in the way of free-living nematode and decomposer mite relationships. Further research is necessary. Geltzer (1963) working in Russia reported plant species variability in aggregations of five genera of soil protozoans (Amoeba). Associations with six crops were as follows: wheat (large aggregations of 4 genera), oats (large aggregation of only 1 genus), flax (large aggregations of 2 genera, and a small aggregation of another), vetch (moderate aggregations of 3 genera), lettuce (small aggregation of 1 genus) and peas (large aggregations of 3 genera). Particular root exudations and microbial differences appear to account for the significant differences observed. Further field and concurrent laboratory studies of the microbial-invertebrate microcommunities associated with rhizospheres of all crop species need to be pursued. Many interspecific interactions are possible which may be beneficial to crop production.

Considering crop-faunal relationships on a larger scale via samples taken from actual farming sites under production, soil invertebrate communities still appear crop specific. Working in plastic tunnel greenhouses in Egypt, Tadros and Saad (1980) found that soil faunal abundances from large plantings of cucumbers were considerably greater than those from tomato plantings. Variables responsible for such differences and relationships to productivity are yet to be elucidated.

Clemen & Pedigo (1970) sampled actively farmed fields of corn, alfalfa and permanent pasture (comprised of clovers, bird's-foot trefoil, grasses and several forbs) during the summer months in Iowa. They mainly analysed for differences in the collembolan communities between sites based upon Christiansen's (1964) conclusion that Collembola are probably least likely of all soil arthropods to be affected severely by cultivation. Their findings showed considerable differences in the springtail community structure with very high coefficients of dissimilarity between all sites. The diversity scheme was pasture > alfalfa > corn with the pasture exhibiting the greatest equitability. They attributed the strong dissimilarity between corn and the other sites to a relatively low soil pH, low moisture availability and the severe disruptions by cultivation practices. Dissimilarity of the alfalfa community from the other sites was mainly caused by the drastic microclimatic shifts due to mowing, drying, and removal of the hay crop. As noted before, ecological ramifications of the monocultural vs. heterocultural effects (corn vs. pasture) and the increased microarthropod populations associated with presence and greater physical structure of litter are supported by Clemen's and Pedigo's data.

Data from citricultural practices in South Africa support Christiansen's contention. They show that Collembola responded by increasing from $1000/m^2$ on an UT field to $14,000/m^2$ on the same field type planted with citrus trees, but receiving no pesticide applications (Oliver and Ryke 1969). Springtail increases were likely due to the decrease in predaceous mites (that feed on Collembola) from $6500/m^2$ to $900/m^2$ caused mainly by the agricultural impact.

Soil Agrocommunity Function. Golebiowska and Ryszkowski (1977) working in Poland recorded for five years the functional aspects of a field subjected to a simple rotation: rye for grain, rye for green forage and potatoes (Table 4). Of the biotic community present, they found that bacteria dominated over fungi and actinomycetes. Soil Protozoa and Lumbricidae (earthworms) comprised 90% of the average standing crop of invertebrates. Soil mite populations were very low in all three crops. The functional decomposer niche vacated by a large number of mites with small biomass was filled by a small number of earthworms with large biomass in the same way as reported by Dindal et al. (1977), when they dealt with another type of human environmental influence. Bacterivorous nematodes dominated over all other types of roundworms even plant parasitic forms. Comparisons of all these data suggest interesting patterns related to production-respiration ratios, energy and nutrient fluxes and the pooling potential associated with specific crops. This type of total functional and structural analysis is just not available for most crops in the U.S. and the rest of the world. For this reason, a concerted effort to collect such information must occur before effects of soil organisms on crop productivity and vice versa can be determined, applied and fully appreciated.

GRASSLANDS, PASTURES, MEADOWS, RANGELANDS, OLD FIELDS

Definition. Within these vegetative categories exhibiting similar ecological systems, two extreme conditons are observed - the old field sites and the pasture lands. Certain old field herbaceous communities would not

Table 4: SUMMARY OF SOME FUNCTIONAL ECOLOGICAL ASPECTS OF AN AGROECOSYSTEM (average annual Kcal/m^2)

	RYE FIELD	RYE PLUS POTATOES
TOTAL PRIMARY PRODUCTIVITY	5418	6730
INPUT OF PLANT LITTER INTO SOIL	1880	4037
TOTAL HETEROTROPH RESPIRATION	2500	4000

(after Golebiowska & Ryszkowski 1977)

be considered by some to be related to agriculture. They are merely successive seral stages formed in an area after some environmentally catastrophic event or human manipulation that left the land denuded. In these cases all facets of pioneer biotic productivity will eventually cause the stabilization of the area or the meager beginnings of soil formation. On many of these sites the secondary productivity of wildlife populations adds considerable diversity and value to the ecosystem. Early successional communities growing on marginal land not appropriate for food production will eventually revert to the climatic climax of the area - a forest or a complex grassland. Research is being conducted on such marginal, reverting lands as sites for the managed rehabilitation and stabilization of municipal sewage sludge applications and sewage effluent irrigation (Dindal, Geis, Hartenstein and Mitchell, unpublished). Decomposition processes and functions of soil biota are of prime importance in such land manipulations. Details will be discussed briefly later.

The other vegetative extreme is the planned and agriculturally managed pasture where the primary productivity of certain plant species and the secondary productivity of livestock are the main objectives. Similarities exist between the vegetation from one extreme to the other. On any of the sites the grass family (Graminae) and/or the legume family (Leguminosae) dominate along with the possibility of some forbs such as the composite family. The Compositae commonly reaches codominance levels with the Graminae in the more wild, natural successional stages. Just as plant, soil-faunal species specificity was apparent in the discussion of crop types, it can also be assumed a strong possibility with these characteristic grassland forms.

Grassland sites of various types are very common in many localities of our country, in Western Europe and other parts of the world. As common as they are and being the subject of much research, Usher (1978) points out that numerous ecological questions are still to be answered, especially regarding soil-faunal succession and structure and function of decomposer communities. Based upon ecosystem approaches, this topic of old field or meadow ecology seems to have been investigated more than other agricultural areas with the possible exception of pesticide ecological studies.

Soil-Faunal Community and Structure. Whelan (1978) in Ireland found that mite diversity in both the litter and soil of 2 and 4 year old fields were less that that from more complex permanent pastures. Since the evenness indicies were rather similar in all cases, the increased change in the acarine diversity was mainly caused by the gradual increase in species richness as viewed temporally. Definite species differences were noted in mites that are adapted primarily as colonizers being most abundant on the 2 year old site, fewer in the 4 year old field and practically absent in the permanent pasture. In the latter the functional niches occupied by the colonizers were replaced by more mite species exhibiting adaptations to more complex microhabitats.

Pastures and Earthworms. Journal articles with titles stating relationships between earthworms and soil fertility in pastures have been published by several scientists, Barley (1959) in Australia and Evans and Guild (1947) and Guild (1948, 1951) in Scotland and Rothamsted. In all three research sites the species complex known as Allolobophora (=Apporectodea) caliginosa and Allolobophora longa were the dominant species, oftentimes comprising 50% or more of the earthworms present. These were on areas established for 6 years or more. At Rothamsted, plowed permanent pastures reseeded with grass after 1-2 years were dominated by Eisenia rosea. And in very old permanent pastures the percentage of Allolobophora nocturna gradually surpassed A. (A.) caliginosa.

In Australia, A. (A.) caliginosa dominates along with E. rosea after 6 years or more; incidently these species were introduced into Australia just as they have been in the U.S. Also in these 6 year and older permanent pasture sites an average of 80 grams of earthworm tissue/1000 grams annual (dry wt) production of herbage was recorded near Adelaide; after fallow and cropping in a 2 year rotation of old field/fallow/wheat only 20 grams of earthworms/ 1000 grams annual (dw) herbage production was observed. In permanent pastures in Palmerston North, a constantly wetter section of Australia, 160 grams of earthworm/1000 grams of annual (dw) herbage was produced.

Unfortunately, the titles of the above citations are misleading since other than reference to pH optima (Guild 1948) and some relative production figures by Barley (1959), the articles present very little on soil nutrient fertility factors as implied.

In any case, more pasture soil fauna research and earthworm biomass/ field litter production comparisons should be undertaken in our country.

Decomposer Food Web Dynamics. A review of the role of soil fauna in grassland decomposition led Macfadyen (1978) to suggest the following hypotheses to investigate in relation to dynamics of decomposer trophic levels: 1) to describe the properties of soil invertebrate feces as substrates for microbes, 2) to clarify the "microbe stripping" concept in terrestrial isopods, potworms and others as a food source, 3) to determine the true nature of the assimilate which passes through guts of soil fauna, and 4) to apply systems analyses to help elucidate the movement of plant nutrient substances through the grassland ecosystem relative to as many variables as possible. These suggested objectives have significance to the total understanding of soil microbial-faunal relationships associated with all agricultural practices.

Working in natural meadows in Poland, Kajak (1980) reports that the abundance of predators is determined by the biomass of the lower trophic level. She found that meadow management procedures if too drastic will ultimately cause decreases in density, biomass and diversity of major polyphagous predators (spiders, ground beetles, rove beetles) found in the soil and litter. Response to such a predator decrease results in a rather immediate population explosion of, 1) fungivorous Collembola which aid in organic matter decomposition and more rapid energy and nutrient recycling than before, and 2) phytophagous mites and insects that may reach pest proportions attacking the crop species being managed.

Energetics of Soil Biota. One excellent in-depth treatise on all the functional aspects of the entire soil biotic community within a grassland has been authored in Sweden by Persson and Lohm (1977). It definitely should be used as a pattern and stimilus for similar types of complete functional studies in the U.S. and other countries.

Grazing Effects. Herbivore grazers impart indirect detrimental effects on soil fauna (Wallwork 1976). Among macroinvertebrates -isopods, centipedes, millipedes, spiders, ants and beetle adults are all significantly reduced in an English grassland (Morris 1968). King and Hutchinson (1976) observed similar indirect effects on soil microarthropods by sheep grazing for 2 years in pastures in Australia. They found that high numbers of sheep severely reduced surface Collembolan populations; moderate to small numbers of grazing sheep reduced mites, potworms & nematodes. Soil fauna were affected indirectly by compaction with loss of soil pore space, changes in soil temperature, litter, above ground and below ground biomass.

As was seen with cultivation impacts, Collembola are very resilient and affected only under the most stressful extremes.

FENCE ROWS, HEDGEROWS

Maintenance of hedgerows was considered a cultural practice beneficial to soil fauna by Wallwork (1976). Although shown to act as a refugium for pest arthropod species, the high diversity (high species richness) of the predatory invertebrates like ground beetles and spiders has also been shown to be abundant in hedgerows and to be very effective in controlling the pest forms. Even though hedgerows and fence rows have traditionally been more a part of the European landscape, wildlife specialists in the U.S. like Dambach (1948) (working in Ohio) made a thorough study of shrub and grass borders in an attempt to stimulate fence row maintenance. He showed a high population of phytophagous leafhoppers (Cicadellidae) present in the shrub canopy in the summer, but also found equally high numbers of predatoid and parasitoid wasps, predaceous ants and beetles exhibiting three peaks in the summer. In addition, omnivorous bird species (average of 24/border hectare) and insectivorous shorttail shrews (average 15/border hectare) were relatively abundant. Comparing the relative abundance of litter invertebrates (no./border hectare), he found 590,000 in hackberry-elderberry-blackberry shrub borders, 723,000 in osage orange borders and 777,000 bluegrass borders. More specifically, Clemen and Pedigo (1970) showed that the Collembola community was most prominent in unmanaged pasture borders, less so in corn borders and lowest in weedy alfalfa borders. Also the array of springtail populations in each site were quite dissimilar with each other.

At present, all of fence row data should be further analysed as Clemen and Pedigo did, and then hypotheses tested to see just what these differences mean.

NO-TILL AGRICULTURE

Novel Approach. Various synonyms such as *non-till*, *no till*, *untill* and *direct drilling* have all been used to refer to the new technique of no-till grain production. Since this practice involves a specialized manipulation of an old field or a grassland site, perhaps data about soil organism impact on productivity may have application to this new procedure. Using no initial plowing, seeds are planted or drilled directly into the formerly grass site; also a herbicide application is usually made to the site. This method moves more closely toward a heterocultural vegetative community and, therefore, should exhibit faunal characteristic trends of more complex systems. Also some very preliminary results from Stinner and Crossley (1980) show another trend that the more intact soils of no-tillage agroecosystems should be more conservative of nutrients such as nitrates.

The Soil Invertebrates Respond. Working in loess soils in Germany, Ehlers (1975) published some of the first data on soil ecology of no-till fauna. Comparing the plow horizons (Ap) in tilled and 4 year no-tilled sites the number and percentage volume of earthworm channels doubled relative to the tilled site. Since the physical cumulative water intake within earthworm channels is related directly to channel diameter, Ehlers found that channels in untilled sites allowed passage of tension-free irrigation water (at the rate of 1 $L/m^2/min$) from open burrow ports on the soil surface down to a maximum depth of 180 cm. Channels in tilled sites were not effective.

Edwards and Lofty (1978) isolated intact soil profiles from sites having had six successive no-till cereal crops and from two plowed areas. After fumigating these laboratory microcosms, various species of soil arthropods and earthworms were introduced into the sterilized profiles, and the invertebrate effects on root growth were monitored after 89 days. Root growth and distribution was correlated with animal activity zones. In microcosms inoculated with arthropods, maximum root growth occurred in the uppermost 5 cm of soil where most of the arthropods live. The earthworms, _Lumbricus terrestris_ and _Alloloborphora longa_ produced deep semi-permanent burrows through which greater root length development was observed. Shallow working earthworms

(Allolobophora caliginosa and Allolobophora chlorotica) that do not produce permanent burrows seemed to cause the enhancement of root growth within the top 20 cm of soil - their optimum zone of activity. In plowed soil without animals, root growth was throughout the profile. Edwards' and Lofty's conclusion was that soil invertebrates have an important role in promoting root growth under no-till practices. Their observations of burrow-root distributional relationships have even more meaning when combined with the facts about earthworm castings (Lunt and Jacobson 1944). Casting can be incorporated within burrow walls. They have higher pH, more nitrates, more total and exchangeable Mg, more available phosphorus and greater base capacity than surrounding soils.

In Georgia, a major comprehensive project is being conducted comparing sorghum production in an old field in a conventional tilled site and in a no-till area. This research has provided much knowledge of interest regarding agricultural soil ecology (Blumberg and Crossley, in review, Stinner and Crossley 1980, and Weems 1980). Similarity indicies of the soil surface arthropod communities in each of the three plots showed that they were considerably distinct from the other; any two communities had less than 30% of their species in common. The old field macroarthropod community was most similar to that in the no-till sorghum site especially during drought stress periods and after sorghum heads had developed. As a specific example, 30% of the individual arthropods and 15% of the species in the no-till site were spiders and these numbers were very similar to the 22% of the individuals and 17% of the spider species found on the old field; in contrast, only 11% of the individuals and 8% of the species were spiders on the conventional tilled plot. Among these there was a three fold increase in wandering spiders in the no-till over the tilled area. Also, Weems (1980) showed that soil microarthropod numbers and species diversities were very similar between no-till and old field sites, but parameters for both of the sites were significantly different ($Pr < 0.1$) from the lower values obtained from the conventionally tilled area.

Sorghum productivity (in biomass) from no-till and tilled sites was not significantly different despite the general expectation of a higher pest population associated with no-tilled sites. Finally Blumberg and Crossley suggest that their preliminary results show that an insecticide stress subjected to the no-till site may cause pest populations to increase. This no-till project at UGA was initiated in May 1978 and is still underway.

Other preliminary research is underway in Michigan comparing several types of traditional plow techniques, the moldboard and the chisel, with no-till procedures in the production of field corn in an old grass sod field (Shams, Snider and Robertson 1980). Grain yields from all sites were similar ranging between 13,000 and 14,000 kg/ha. Also within the surface 5 cm of soil, no-till sites supported the greatest number of collembolan and mite populations.

After all the future data from UGA and MSU are collected, synthesized and analysed much new exciting information is in store for those interested.

PRESCRIBED BURNING

Managed burn techniques are being gradually accepted and used on forest plantations; occurrences of natural fire in climax grasslands are also being accepted as a part of the selection pressure stress of these areas. And the use of fire on agricultural land has been adopted by regional farmers for various reasons. Effects of fire on soil organisms have been studied mainly on forested lands. Contradictory results have been obtained due to the many variables such as fire frequencey, nature of the fuel, temperatures attained and length of burn to mention only a few. Some of our work (Metz and Dindal 1975, Dindal and Metz 1977) evaluating effects of periodic and annual burns on Collembola in pine plantations suggests hypotheses regarding community structure modification that should be tested whenever agriculturally related burns are adopted. Again supporting Christiansen's (1964) belief, springtails in general can withstand major periodic stresses, in this case fire, with only minor modifications in community structure.

WATER DYNAMICS - DRAINAGE AND IRRIGATION

No data on soil invertebrates related to the major irrigation practices in this country could be found. With the extensive use of center pivotal irrigation in the Midwestern States and the many other types of irrigation systems in operation in the Southwest, the research stage is set. Numerous field treatment and control plots are available, and many soil ecological research objectives need to be tested and soil ecological principles applied.

Land Reclamation by Draining. Drainage of wet soils definitely changes the appearance and function of the earthworm community. In a Lithuanian SSR study earthworm diversity was decreased from seven to three species upon draining. Genera adapted for wet soil conditions such as Dendrobaena and others disappeared (Atlavinytė 1976). As the area became drier and farmed, the anthrophilic species complex of Allolobophora (= Apporectodea) caliginosa became more abundant. The drier condition caused the dominance factor in the earthworm community to increase. Hypothetically, other community structural changes would occur dependent upon how the dry site would be agriculturally managed after it was drained.

Municipal Sewage Effluent Irrigation. As mentioned under the grassland section, many vegetative communities are being considered as sites for municipal sewage waste deposition. Since new rulings will soon forbid dumping of waste materials in waterways and ocean sites, the soil ecosystem is thought of as the next receptacle. One method designed in 1962 to handle part of the problem has been the very farsighted topic of research of Drs. Kardos and Sopper at the Institute for Research on Land and Water Resources at Pennsylvania State University. They proposed to recycle the wastewater, complete with its elemental and nutrient charge, from the local waste treatment plant to various vegetative sites using a spray irrigation system. As a result, they found not only an efficient and effective wastewater renovation procedure, but they also observed in the T agriculturally oriented sites that the vegetative production was considerably enhanced (Sopper and Kardos 1973; Richenderfer, Sopper and Kardos 1975).

Since the soil organisms had not been originally investigated in this wastewater irrigation study, we joined the research team 10 years after the project had been initiated. Our purpose was to assess any impact that the irrigation procedure may have had on the soil invertebrate community (Dindal, Newell and Moreau 1979; Dindal, Schwert, Moreau and Theoret 1977). A reed canary grass hay field, an old field herbaceous site and a mixed oak hardwood forest were all sampled seasonally over a 3 year period. In general, we found the following: 1) soil invertebrates responded both positively and negatively to the selection pressure of wastewater irrigation, 2) generally, mite populations were suppressed by treatment while Collembola exhibited periodic seasonal increases (again supporting Christiansen's [1964] contention that Collembola can withstand stress conditions greater than other microarthropods), 3) total abundance and biomass of earthworms were increased by wastewater irrigation, 4) earthworm communities from T sites were larger and more similar to each other than those communities from UT sites, 5) wastewater irrigation selected for the earthworm Dendrobaena in all vegetative communities (this was the same earthworm genus adapted to wet soil that was found to disappear after site drainage), 6) functional niche replacement among soil invertebrates was observed where potential agents of litter-organic matter decomposition were shifted by effects of irrigation from many organisms with low biomass (mites) to those with greater biomass (earthworms), 7) a direct relationship existed between worm biomass and soil porosity, and 8) formation of specific-sized water-stable soil aggregates was related to presence and population increases of specific species of earthworms.

Success But Caution. As a method for enhancing wastewater renovation, the soil chemical and physical structure and the dynamics of invertebrate decomposer processes, this irrigation system is sound and viable. Crop production at the same time, can also be improved if the wastewater is free of industrial pollutants such as heavy metals. Caution must be used, therefore, if the wastewater treatment plant services a municipality having a large input source of organic toxicants or heavy elements. No active or potential agricultural lands should be used if a toxic danger exists. Irrigation in this case must be confined to marginal successional lands reverting back to forests or established forest lands where the residence time of recalcitrants and toxic materials will be long, thus resulting in a gradual dissipation over time and space. Temporal and spatial longevity of recalcitrants and toxic substances can be accomodated on marginal lands and forests by being microscopically locked biologically, chemically and/or physically onto active bonding sites on soil organic matter and humus horizons, on clay mineral complexes, within tissues of relatively long-lived trees and shrubs, and finally, within tissues of components of the decomposer food webs which are not likely to make their way into human food chains.

EFFECTS OF FERTILIZERS

Fertilizers have considerable, although little-studied, effects on terrestrial invertebrates, probably chiefly through alterations in plant species diversity and composition (Morris 1978).

A Hypothesis. Hurd and Wolf (1974) working in several abandoned old fields in central New York, subjected the T site with a 10-10-10 N PK fertilizer which they classified as a "nutrient enrichment perturbation." Considering fertilizer in this way provides an objective ecological approach; the fertilizer effect was termed a "deflection" from the UT norm. After collecting and analysing the arthropods they concluded that 1) the magnitude of deflection caused by the fertilizer perturbation was decreased up the arthropod trophic levels from herbivore to higher carnivore levels, and that 2) the rate of response to perturbation decreased up the trophic levels. This provides an interesting scheme to be incorporated and tested in future soil ecological studies dealing with any type of perturbation.

Fertilized Soil Microarthropods? Wallwork (1976) refers to an English study where microarthropods were sampled from a crop of marigolds having several treatments as follows: one with inorganic fertilizer (NPKMg) and the other receiving farmyard manure (31 mT/ha/yr). Microarthropods on the former T site amounted to 15,050/m^2 compared to the UT plot which had 13,378/m^2. The manure T site supported 27,000/m^2 microarthropods; and normally rather obscure taxa like Pauropoda, Diplopoda, Symphyla and Diptera larvae reached more equitable levels.

Edwards (1969) stated that since heavily tilled soils have practically no soil animals present to assist in processes of fertility, these soils must receive inorganic fertilizer additions. Presently, with the ever increasing costs of fertilizers, perhaps an agricultural transition toward heterocultures or no-till systems would be in order so as to attract faunal colonizers and maintain invertebrate decomposers in a natural nutrient recycling - nutrient sink mode.

PESTICIDES

Of all the research conducted in the world on the effects of agriculture practices on soil organisms, apparently none has been studied as much as the effects of pesticides. Also, much of this work has been carried out in the U.S.

However, one of the major problems of pesticide ecology is that it is highly complex to assess (Wallwork 1976). Researchers in the soil ecology of pesticides have had difficulty making generalizations because of the multivariate nature of the subject. These variables include the following: 1) numerous species of biocidal compounds from various chemical families, 2) great differentials of persistence of pesticide compounds in the environment,3) the presence of a diversity of invertebrate types in the communities of different soils, 4) various metabolic products related to the species specificity of organisms in which the pesticides reside or to which biota are subjected, 5) highly variable biological half-lives of pesticides associated with different taxa, 6) many chemical and physical variates found in an agro-soil ecosystem, and 7) the psychological, cultural and traditional agricultural practices of the people who use the pesticides.

And when pesticide-effects data are finally all collected and analysed the biotic responses are equally as variable as follows: 1) soil fauna may exhibit either a direct response to pesticide application or more often an indirect secondary response, 2) not all living organisms are affected in a detrimental fashion as many people think; some soil forms actually increase in number and diversity after being subjected to certain pesticides, 3) certain pesticide residues accumulate in tissues of some soil organisms with no apparent ill-effects, and, of course, 4) certain sensitive species are killed from acute or chronic exposure to biocides. Taking these factors into account collectively, in most all cases the structures and functions of soil communities are modified.

Therefore, considering the multivariate and the multiple-factor nature of this subject an attempt to synthesize the pesticide-soil ecological literature is inappropriate under the format of this report. However, since a synthesis is ultimately necessary, the following listing of citations of the most recent reviews and relevent articles is hereby presented. This provides an initial and immediate source from which statements on soil community patterns related to pesticides may eventually be compiled. These selected references are categorized according to the country in which the work was done. This illustrates the relatively greater amount of research that has been published by the English speaking nations primarily due to the influence of C.A. Edwards. They are as follows: ENGLAND, Thompson and Edwards 1974; Edwards 1965, 1970, 1973; Edwards and Thompson 1973, Thompson and Gore, 1972; Way and Scopes 1965, 1968: CANADA, Broadbent and Tomlin 1980; Smith, Kevan and Hill 1980; Tomlin and Gore 1974: UNITED STATES, Dindal and Norton 1979; Spalding 1978, Douce and Webb 1978; Dindal 1977; Nelson et al. 1976; Dindal, Folts and Norton 1975; Wurzinger and Dindal 1975; Ward and Wilson 1973; Guyer 1970; Davey 1963: INDIA, Bhattacharya and Joy 1980; Edwards, Veeresh and Krueger 1980: BELGIUM, Lebrun 1977: NETHERLANDS, Eijsackers 1978, 1980: NEW ZEALAND, Martin 1976, 1978: JAPAN, Kitazawa and Kitazawa 1980.

Although this massive store of knowledge presently exists, efforts to collect more, and to scientifically compile, relate and analyse those data are the next most important priority. Agroecosystems specialists and practitioners have an imperative need for concrete statements of soil biotic community patterns, such as the similarities and dissimilarities that exist under various potential biocide stresses in the field.

DYNAMICS OF OTHER TOXIC INTRODUCTIONS

Both field and laboratory verification studies are urgently needed in this area of environmental concern related to soil. When toxic wastes are spread on soil or buried they come into immediate contact with the soil biota. Studying toxic wastes is as complicated, if not more so, than pesticide ecological research. Collectively toxic wastes provide a wide spectrum of selection pressures on all living creatures. Some organic toxicants on or in soil will be decomposed or at least modified by the decomposer food web components and associated process. Because of the greater ecological age of forests with the various organisms adapted to decompose a broad variety of compounds, perhaps some toxic wastes will be broken down more rapidly under such sites - a hypothesis that needs pursued. Other compounds are extremely recalcitrant and remain unaltered for long periods. Some recalcitrants that are chemically inert, such as some detergent containers or drinking cups, may ultimately be broken down into smaller units and shapes thus adding structural and surface substrate diversity to the three-dimensional physical patterns in the soil ecosystem. Other recalcitrant compounds not so inert can continue to sublimate, volatilize and disperse throughout the soil microenvironments causing (at this period in our knowledge) unknown effects. Unfortunately, the cause and effect relationships between many of the priority pollutants and soil biota are yet to be investigated.

Heavy Metallic Earthworms. Heavy metals from whatever source can threaten soil biotic systems.

Research in Holland showed how earthworm growth and reproductive capacity was reduced (Rhee 1969), and worms were completely eradicated from soils having copper accumulations in excess of 80 ppm (Rhee 1963, 1967). Although such levels resulted from the indiscriminant and massive use of copper fungicides in orchards, accumulation of copper in the fields also occurs when heavy applications of pig manure are used as organic fertilizer. Raw pig manure can contain as much as 1000 ppm (Rhee 1975). Spread over long periods on a given site the critical maximum of copper can reach 80 ppm soil, and thus become toxic to worms. Interestingly, other preliminary studies show that other heavy metals may accumulate to very high levels in earthworms without being lethal.

Ireland (1975) working in Wales, has assayed effects of various heavy metals on both the gross body processes of earthworms and the histochemistry and histopathology of heavy metals. This type of pioneering cellular and tissue research must be initiated relative to all possible soil organisms and pollutants.

Other workers who have contributed to soil ecology - heavy metal dynamics include Curry and Cotton (1980) in Ireland and Carter, Hayes and Laukulich (1980) in Canada. In the U.S., Dindal, Newell and Moreau (1979) working in Pennsylvania have shown that species specificity and age specificity in earthworms exists in the relative accumulations of copper, zinc and cadmium; also Gish and Christensen (1973) sampling along highways in the Washington D.C. area reported heavy metal concentrations in earthworms was correlated directly to distance downwind from the roads, amount of highway traffic and amount of soil organic matter present.

All of this preliminary information is very interesting, and provides so many potentially useful hypotheses to be tested so that we can understand the dynamics of all types of toxic waste in our land.

COMPOSTING AND BIOTIC SLUDGE - USE TECHNOLOGIES

An Ancient Art Revisited. In agronomic oriented cultures of the past the tradition of composting and its use occupied a very important part of the total life style. Likewise this management of organic matter decomposition if practiced by a majority of the population today could considerably reduce the solid waste problem of many towns, villages and municipalities. Many people are interested in being involved in personal composting practices. For instance, since 1971, more than 60,000 copies of "Ecology of Compost", a small public educational pamphlet, have been requested and sent from the publications office of the SUNY College of Environmental Science and Forestry, Syracuse (Dindal 1971).

Essentailly, compost is no more than an "artificial litter" accumulation.

The same diversity of soil biota that is associated with litter is potentially available for compost processing (see Figure 1). Part of the educational process necessary for effective composting is that the person who is composting realize that the array of little creatures or "bugs" in the compost are all integral components of the system. People oftentimes see these organisms and quickly resort to chemically elegant ways to destroy them. To understand the structure and dynamics of litter in the field is to understand compost - and vice versa!

With the present day reevaluation of our very expensive energy uses and demands, composting practices associated with the potential productivity of gardening and farming should be encouraged. Composting occurs because of the activity of a number of very unique decomposer organisms carrying out vital decomposition processes. Learning to properly manage these processes and the wild "microbeasts" requires some scientific know-how but also demands the observations, imagination and deductions of an artisan. Unfortunately associated with the artistic approach of the past have also been many erroneous tales describing phenomenal powers of compost. However, a compost pile must be envisioned objectively for what it is, a highly intricate and integrated, efficient decomposer microecosystem. Then it will fit very usefully within the environmentally conscious framework of both our rural and urban society.

Earthworms, Compost and Sludge. Fortunately, the attributes of the meager anthrophilic earthworm as a potentially manageable decomposer are being realized. Fosgate and Babb (1972) working in Georgia, showed in a scientific way some of the values and possibilities of earthworms in recycling dairy cattle wastes. The conversion of cow fecal matter to live earthworm tissue was 2:1 (based upon dry weight). Earthworm castings contained about 3% nitrogen. In addition to the special chemical composition, castings are unique physically. They are water stable aggregates comprised of organic material blended with inorganic soil components and as a unit they enhance soil structure. Also different sizes of earthworms produce characteristically sized water stable aggregates (Dindal, Newell and Moreau 1979). So different species affect the structure of the upper soil layers differently.

Much laboratory work and some field research in New York with earthworms and municipal sludge (Hartenstein and Mitchell 1976) resulted in evidence that a stabilized product could be formed which was very similar to topsoil (Mitchell et al. 1977, 1978), and it could be used as a soil amendment. Appelhof (1980) in Michigan reported that household level vermicomposting was very successfully practiced using garbage and lawn and garden debris. The product was then recycled into household plants, local gardens and truck farm plots. Also, both sewage sludge and household refuse has been composted and used on arable lands in Sweden (Lagerlöf and Andrén 1978).

Recycling of sludge (composted or not) on arable soils immediately raises the ominous specter of heavy metal toxicity before us. The realistic chance that these heavy elements can accumulate in food products has caused curtailment of using composted sludge and earthworm castings (from sludge) on agricultural lands. Of major economic importance to farmers is that commercial vegetable processors and canning companies have ceased purchasing any fresh products grown on sludge amended crop lands. Many problems loom!

In an effort to find a workable scheme for potential sludge recycling in the environment and in agreement with Woodwell (1977), we have embarked upon research in the rehabilitation and stabilization of sludge in forests and non-arable, marginal lands reverting to forests. As mentioned under the section on municipal sewage effluent irrigation, using these types of lands and applying reasonable loading rates, in a reasonable rotation scheme, toxic compounds and heavy metal concentrations could possibly be controlled. Relying upon the successional longevity associated with marginal old fields and forests, this condition could ultimately be accomplished through the temporal and spatial dissipation of biodegradable organic compounds and heavy metals into the environment. With well developed and well adapted decomposer microcommunities of forested areas interacting in concert with the temporal and spatial transport and dissipation factors, there could possibly be minimal if any effects on resident flora, fauna or humans. And the human food webs would not be involved.

Preliminary results show complete stabilization and incorporation of sludge (heavy applications at the rate of 450 MT/ha, 30% solid) into the soils of northern hardwood forests. This occurred within 7 months (October through April) even in the midst of winter and seemed to be mainly due to the activity of native earthworm populations (Hamilton, Dindal, Mitchell and Parkinson, in manuscript). Effects of other soil fauna are being analysed.

SOIL VERTEBRATE IMPACTS ON AGRICULTURAL LANDS

Common views of vertebrate impacts on agricultural soil ecology are negative activities such as making burrows in fields into which farm machinery become entrapped or the enormous amounts of grain that small mammals eat. As pointed out by Darwin (1881) and Taylor (1935) the organic matter incorporation and accumulation of excreta, hair, skin, feathers, scales and nesting materials into soils by vertebrates has had a great beneficial influence on the structure and composition of various soils. Associated with each species of actively burrowing small mammal , for example, is a microcommunity of decomposer invertebrates. Some symbionts like obligatory parasites are highly specific to the mammal. Others are generalists which merely gain entry into the deeper soil horizons via the burrow system. Still other decomposer invertebrates act upon the organic debris within burrows increasing surface area which is advantageous to microbial colonization releasing and recycling nutrients and energy and further incorporating organic matter with mineral materials. In this way vertebrates act as phoretic agents transferring biotic decomposers from site to site over relatively long distances.

Holistic field studies of invertebrate-soil vertebrate-plant productivity associations are practically non-existent. Multivariate statistical methods should aid in this type of important investigation.

IV. CONCLUDING COMMENTS

Applied Soil Biology: A Research Imperative in the United States

Soil ecology is coming of age in our country, but it needs to be nurtured in order for it to develop to the maturity level of sound concepts, principles and reasonable predictability. Sound principles are necessary before soil macrobiotic data can be successfully related to agricultural production and applied to other land-use practices.

Even though some research on agricultural-soil ecology has been conducted in the U.S., the proportion within this specific discipline relative to other phases of advanced agricultural research has been very limited. What data base that was available from our country was included in this assessment report. At best it was fragmentary even in pesticide ecology area where a fair amount of the work has been done in the U.S. Some of the foreign information on soil biology related to agriculture was reviewed to add continuity and structure to the discussion of U.S. data.

Soil in our country, if continually abused without educational and scientific judgements to guide decision-making may very well become one of our major limiting factors. Such a germinating discipline as agricultural soil ecology in our country, therefore, requires an organized, coordinated effort for it to bloom into the type of sound data base needed for a a secure, applicable, scientific foundation.

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